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CARGO FIRE HAZARDS AND HAZARD CONTROL FOR THE OFFSHORE BULK FUE--ETC(U)

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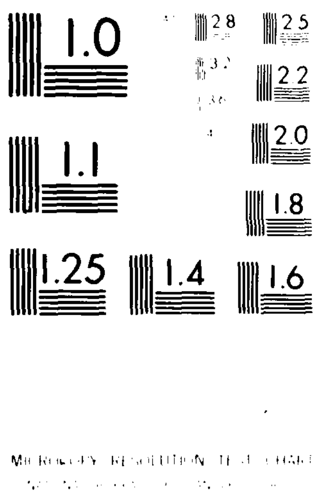
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CIVIL ENGINEERING LABORATORY
Naval Construction Battalion Center
Port Hueneme, CA

Sponsored by

NAVAL FACILITIES ENGINEERING COMMAND

CARGO FIRE HAZARDS AND HAZARD CONTROL FOR THE OFFSHORE BULK FUEL SYSTEM (OBFS)

June 1980

An Investigation Conducted by:

ENERGY ANALYSTS, INC.
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This study evaluates potential cargo fuel spills, spill fires and equipment available to mitigate fuel spill hazards at an off-shore bulk fuel supply installation. Potential cargo spill sources, probabilities and volumes are calculated. Consequences of these spills assuming spill ignition are quantified. Existing fire protection equipment aboard tankers is evaluated to determine the ability of this equipment to control identified spill fire conditions. Where

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existing fire fighting systems are found to be inadequate additional fire mitigation systems are recommended. Logistic support, manpower and training needed to maintain the recommended spill control systems are detailed

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TABLE OF CONTENTS

TABLE OF CONTENTS
(CONTINUED)

TABLE OF CONTENTS
(CONTINUED)

LIST OF FIGURES

LIST OF FIGURES
(CONTINUED)

LIST OF FIGURES
(CONTINUED)

LIST OF TABLES

LIST OF TABLES
(CONTINUED)

LIST OF DRAWINGS

SECTION 1

INTRODUCTION

The U. S. Navy is evaluating an offshore bulk fuel supply system for refueling vehicles and aircraft involved in amphibious assault operations. The bulk fuel supply system addressed in this study consists of a tanker containing refined fuels tied to a single point mooring (SPM) offshore of the assault beach. Fuels would be transferred from the tanker through hoses to the SPM, and then through an underwater pipeline to beach storage facilities.

Any time liquid fuels are being transferred there is the potential for a spill. Spills of hydrocarbon fuels onto water can produce a serious fire hazard. If the bulk fuel supply system is involved in a fire, the fire can do major damage to the tanker, transfer hoses and SPM. Given the mission of the offshore bulk fuel supply system, the potential consequences of fuel spills and fires are of special concern.

This study addresses the potential for cargo spills from the offshore bulk fuel supply system (tankers, hoses and SPM). The potential volume, location and frequency of cargo spills are dependent on the design features of the tanker, tanker maintenance, cargo handling procedures, etc. In this study, a T3 tanker and a Sealift class tanker were used as reference data bases for spill and fire fighting system analysis. The SPM spill safety analysis was predicated on the IMODCO designed, dedicated SPM.

Cargo spill failure modes for the tanker(s) and at the SPM are identified. Using these failure modes in conjunction with equipment failure rate data and design cargo transfer rates, spill probabilities and volumes are identified. The potential consequences of fires subsequent to these spills are quantified.

The ability of existing shipboard cargo handling systems and fire protection equipment to limit the size of spills and control cargo fires has been addressed. Where deficiencies in existing system spill/fire control systems have been identified, methods to correct these deficiencies are defined.

Specific recommendations include:

1. Methods of spill detection and reliability/availability of these systems.

2. Techniques for isolating and shutting down cargo transfer equipment quickly.

3. Reliability and maintainability of cargo transfer equipment.

4. Potential cargo spill fire hazards and the systems needed to control these fires.

5. Fire fighting systems maintainability and reliability.

6. Required crew training for operating spill control and fire fighting equipment.

SECTION 2

DESCRIPTION OF CONSTRAINTS AND APPLICABLE CODES

This study is predicated on specific mission performance criteria, tanker design specifications, IMODCO SPM design features, and existing codes for tankers and tanker-SPM operations. The following presents a summary of these design constraints.

2.1 Mission Performance Criteria

Pursuant to the contract statement of work "Investigation of Fire Protection Requirements in the Amphibious Objective Area" Number 79-0021 and dated May 25, 1979, the offshore bulk fuel supply system should be designed for the following conditions:

1. Sea swell wave height of 6 feet with 18 second period.
2. Installation in sea state 3.
3. Operation in sea state 5 with winds to 30 knots, water currents to 4 knots.
4. Survivability in sea state 6, with winds to 75 knots, and water currents to 4 knots. Survivability in hurricane conditions when given 24 hours' notice (100-knot winds and 35 foot significant wave heights).
5. Operations in air temperature from -28° to +65°C.
6. Operational in all varied environmental conditions from polar to tropical extremes.
7. Maximum beach fuel delivery rate = 1,600 gallons per minute.
8. Tanker to SPM delivery hose size = 10 inches.
9. Frequent make and break connections at the interfaces between the supply and storage tankers.

2.2 Tanker Data

The specific tanker that will be utilized in the offshore bulk fuel supply system has not been identified at this writing. However, for this study ships from two classes of tankers, T3 and Sealift, were used to provide a reference data base. A T3 tanker, the USNS Taluga, was surveyed for this study by Energy Analysts' staff on August 24-26, 1979.

A Sealift Class tanker, the USNS Sealift Atlantic, was surveyed on November 15, 1979. Ship surveys by Energy Analysts were restricted to fire fighting systems and cargo handling equipment.

2.2.1 Cargo Handling Systems - USNS Taluga

The T3 tanker USNS Taluga is a 16,000 ton vessel commissioned in 1943. The Taluga is equipped for at sea refueling operations. A basic description of the Taluga is presented in Table 2-1.

The Taluga has nine main cargo tanks numbered 1 to 9 fore to aft. Tank 1 is divided into two compartments and the remaining tanks each have three compartments. Tanks 1-4 are located either beneath or forward of the amidships bridge. Tanks 5-9 are located between the amidships bridge and forward of the aft machinery area. Each cargo tank is vented via the cargo tank hatches to vent masts located along the ship's deck. Vent piping runs atop each tank.

The Taluga, as shown in Figure 2-1, has two cargo pump rooms. One pump room is located amidships and one aft of cargo tank 9. The numbers and types of cargo pumps and pumping rates are shown in Tables 2-1 and 2-2, respectively. Suction piping to the pump rooms is located in the bottom of the cargo tanks. Figure 2-2 shows the general layout of suction piping in the tanks. Deck piping for the cargo transfer system is shown in Figure 2-3. The deck piping is physically located between the aft machinery area and amidships bridge house.

Figure 2-3 also shows the location of cargo transfer stations aboard the Taluga. At each hose connection position, the ship piping contains two shutoff valves just prior to the hose connection fitting. At each of these stations, one of the two valves is a quick closing valve. Some of the quick closing valves are operable from the 01 deck using reach rods. The reach rod handles are located above their respective valve and can be accessed through hatches in the 01 deck. Several of the quick closing valves are pneumatic and are operable from a valve immediately adjacent to the quick closing valves. Below each fuel transfer station is a drip tray to catch small spills. The dimensions of the six drip trays and the type of quick closing valve at each station are summarized in Table 2-3.

The Taluga cargo transfer system is operated manually and the operation is manpower intensive. As an example, during

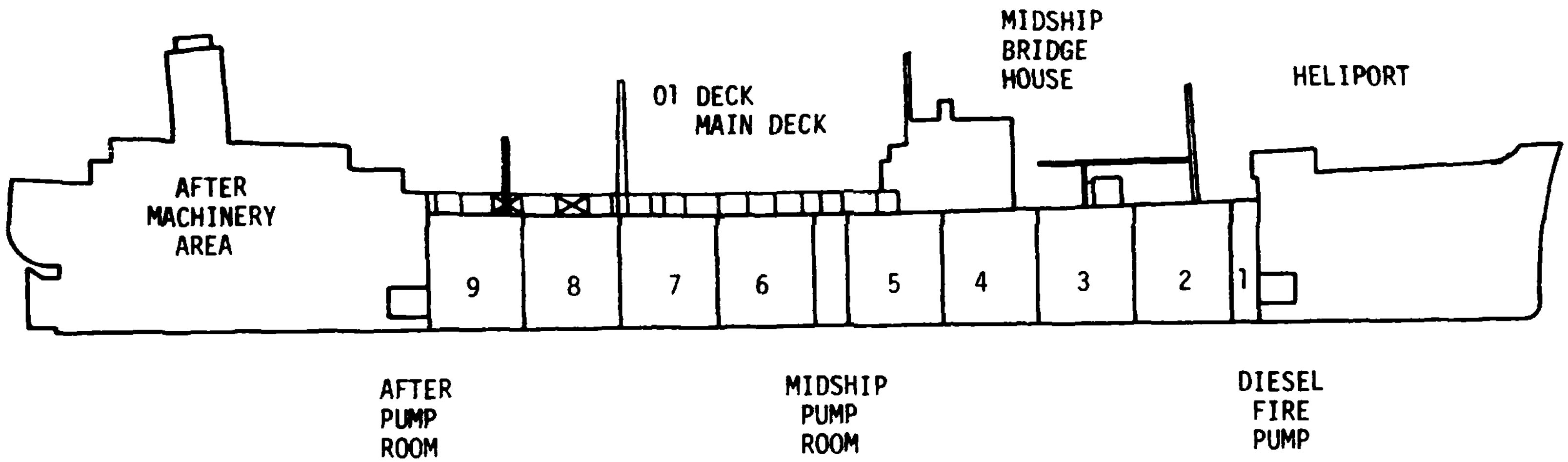


FIGURE 2-1. SCHEMATIC CROSS SECTION OF THE USNS TALUGA

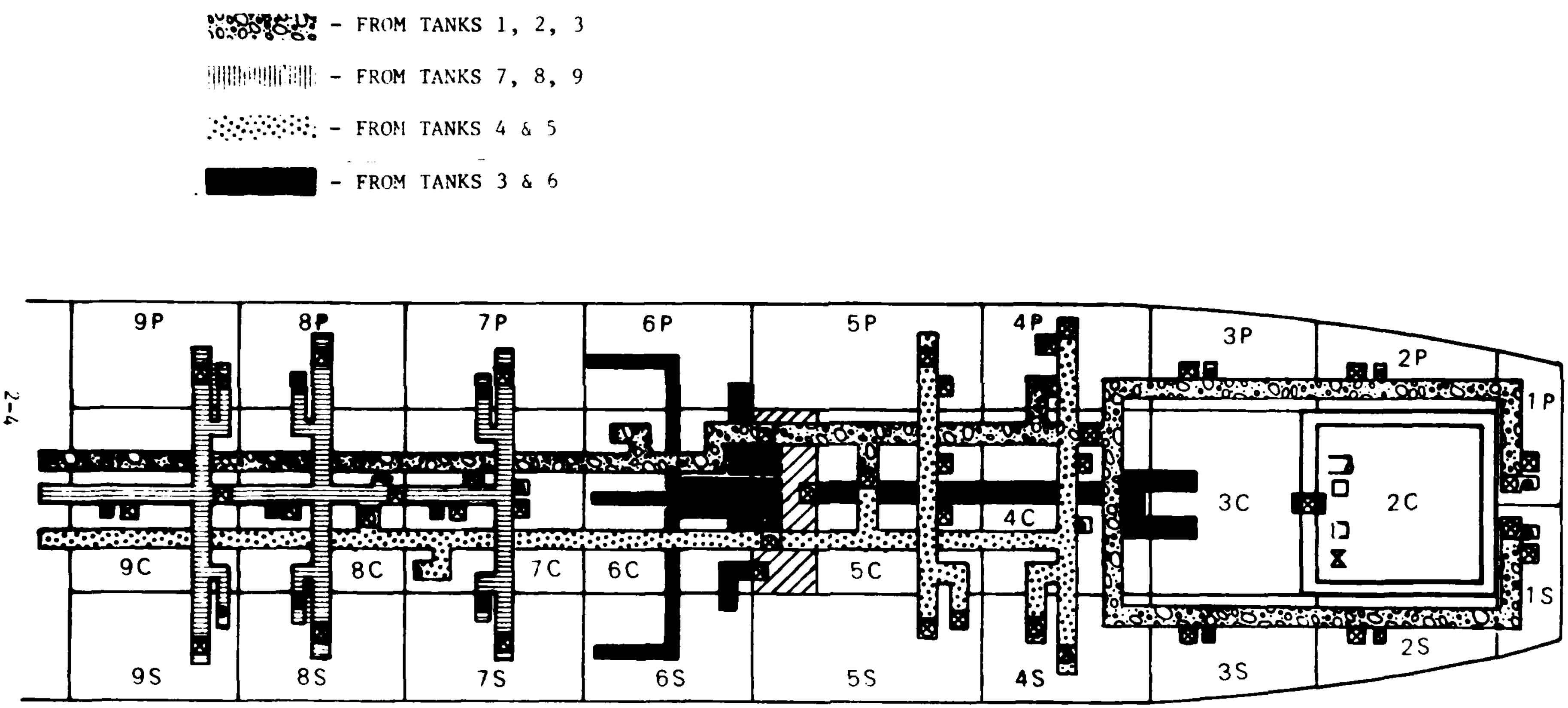


FIGURE 2-2. SUCTION PIPING LAYOUT - USNA

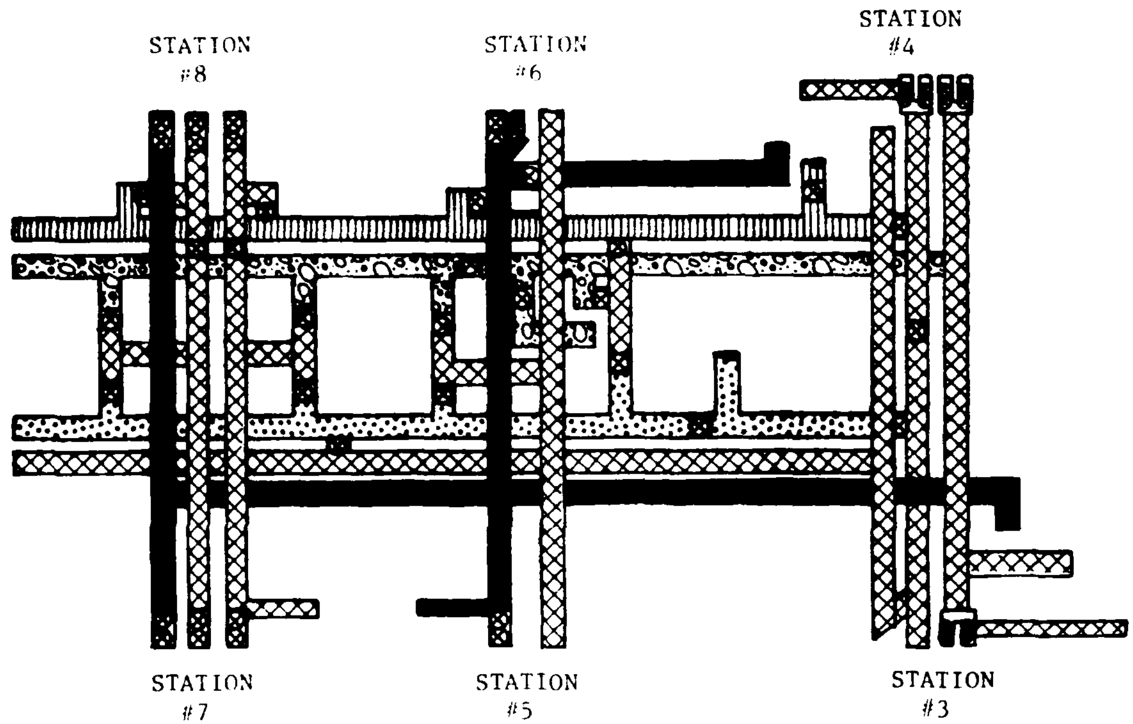


FIGURE 2-3. CARGO TRANSFER DECK PIPING - USNS TALUGA

TABLE 2-1

DIMENSIONS OF TANKERS SURVEYED

	TALUGA - T3	ATLANTIC SEALIFT
Length-overall(ft)	525	587
Beam(ft)	68	84
Cargo Capacity(bbls)	138,000	2,225,000
Number of Main Cargo Compartments	9	7
Number of Cargo Compartments	26	21
Number of Cargo Pump Rooms	2-midship and aft	1-aft
Number of Cargo Pumps		
Midship-main pumps	2-positive displacement	-
-stripping	1	-
Aft-main pumps	3-centrigual	4-centrifugal
stripping	2	1
Cargo Pump Operation Controls	Manual	Manual

TABLE 2-2

CARGO PUMPING CAPACITIES

TALUGA

PSI	JP-5 (gal/min)	DFM (gal/min)
40	1500	1500
45	1600	-
50	1700	1600
55	1850	1650
60	1950	1700
65	2250	1750
70	2500	1800
75	2550	1850
80	2600	1900
85	2700	2000
90	2750	2200
95	2800	2600
100	3000	-

Cargo Pumping Capacities - Sealift Atlantic

Each of Four Pumps - 4200 GPM at 125 TDH

TABLE 2-3

DRIP TRAY AND QUICK CLOSING VALVES AT TALUGA

FUEL TRANSFER STATIONS

Station Number	QUICK CLOSING VALVES		DRIP TRAY			
	Pneumatic	Mechanical	Width	Length	Depth	Volume
3	-	2	26 in	60 in	30 in	203 gal
4	-	2	34	132	105	204
5	-	2	36	60	22	206
6	1	1	42	72	14	183
7	2	2	36	90	15	210
8	1	2	42	72	14	183

fuel transfer from the aft pump room, one man is stationed in the aft pump room, one man in the engine room to operate the turbine drives on the pumps, and at least one man is located at each operating transfer station. All valves must be manually operated and all connections manually made. Key personnel can communicate via a dedicated voice powered communication line. In the event of an emergency during cargo transfer, the cargo transfer system must be manually shutdown. Due to the number of people required on deck to handle cargo transfer operations aboard the Taluga and the location of these people, any cargo spills of significance would be quickly detected and cargo transfer shutdown initiated.

2.2.2 Cargo Handling Systems - USNS Sealift Atlantic

The Sealift class tanker USNS Sealift Atlantic is a 25,000 DWT vessel. The Sealift Atlantic is equipped for point to point cargo transfer operations. It does have at sea cargo transfer capability but this system is not used on a regular basis. A basic description of the Sealift Atlantic is presented in Table 2-1.

The Sealift Atlantic has seven main cargo tanks numbered 1 to 7 fore to aft. Each cargo tank is divided into three compartments. All cargo tanks are forward of the bridge. Each cargo tank is vented via a vent valve on each cargo tank hatch.

The Sealift Atlantic has one pump room immediately forward of the bridge. The number of and types of cargo pumps and pumping rates are shown in Tables 2-1 and 2-2. As with the Taluga, suction piping to the pump room is located in the bottom of the cargo tanks. Figure 2-4 schematically shows the layout of cargo piping aboard a Sealift class tanker.

The two Sealift Atlantic cargo transfer stations are located amidships. The shutoff valves just before the transfer hose and/or transfer arm connections are all manual valves; the valves are not quick closing valves. Under both cargo transfer stations are drip trays. Each drip tray is 2 ft x 18 ft x 2 1/2 ft deep.

The Sealift Atlantic cargo transfer system is all manually operated. Pump room valves can be operated either from the pump room or manually from the deck. Personnel are not normally in the pump room or on dedicated cargo transfer watch during cargo transfer.

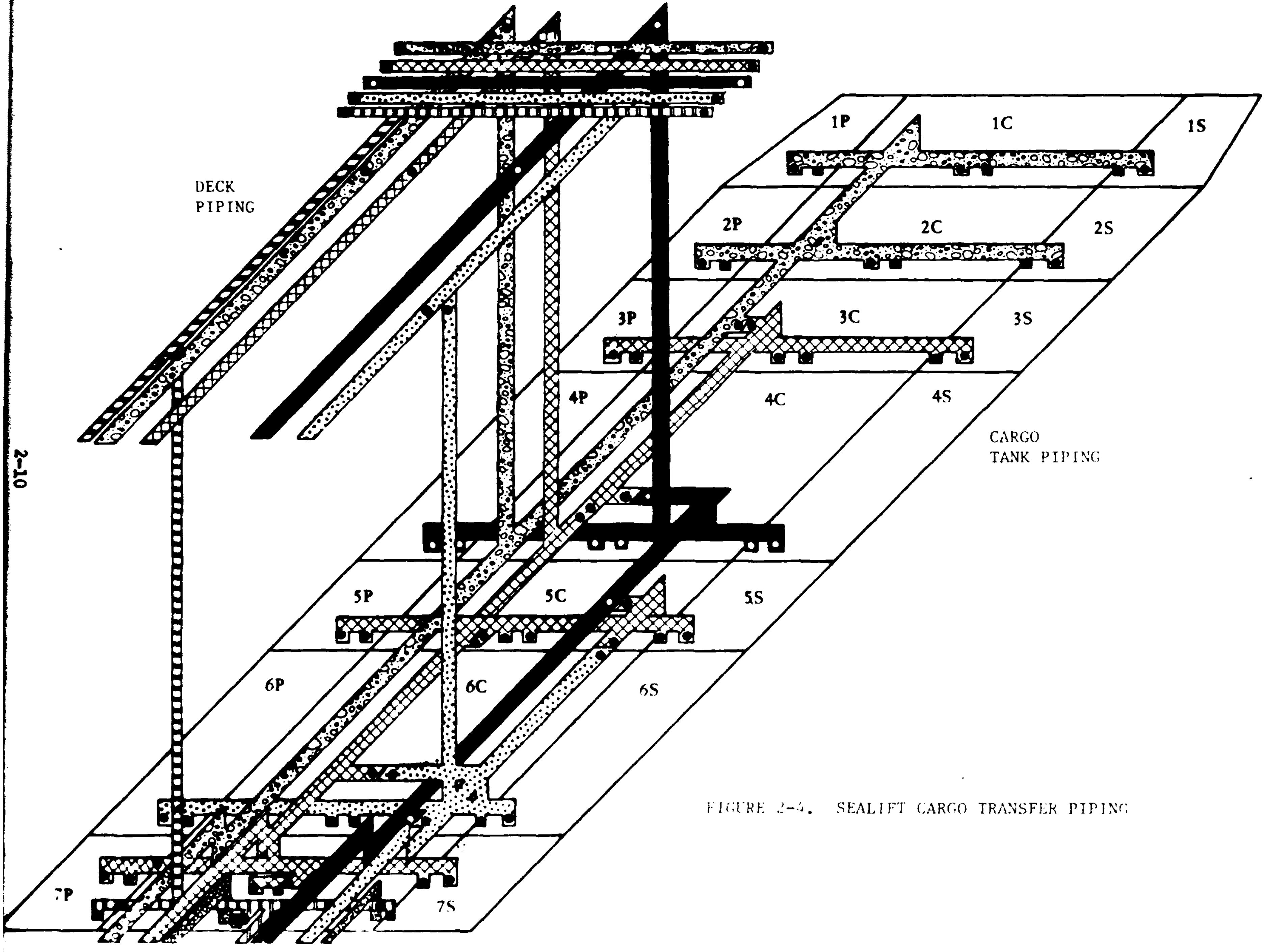


FIGURE 2-4. SEALIFT CARGO TRANSFER PIPING

2.2.3 Fire Fighting Systems - USNS Taluga

Table 2-4 lists the fire protection systems aboard the Taluga that could be available to fight cargo spill fires. The primary cargo fire fighting system is the fire water system.

Fire water is distributed along the main deck of the Taluga via a 6-inch diameter fire water main located along the centerline of the deck and running from the aft machinery area and forward to the standby bilge and fire water pump room. Every fifty feet along the deck there is a 2 1/2-inch hose line connected to the fire water main. Every one hundred feet along the deck there is a block valve on each side of the hose connection and strainers.

As shown in Table 2-4, there are three independent AFFF foam systems aboard the Taluga. Each foam system has its own concentrate tank, proportioning pump, and backup charge of concentrate. Fire water for foam production is supplied from the fire main.

The Taluga helipad, as shown in Figure 2-1, is forward of the cargo tanks and well removed from deck cargo transfer piping. The primary function, of the AFFF unit at the helipad is to fight helipad fires. However, this AFFF system could be used to fight cargo spill fires at tank vent masts forward of the amidship bridge. The fires could occur if the cargo tanks were overfilled.

The foam system just aft of the amidship bridge is identical to the helipad foam system. This foam system could be used to fight drip pan fires at cargo transfer stations #3 and #4 and spill fires on the deck and between these two transfer stations (see Figure 2-3).

The aft foam station provides fire fighting foam to the engine room and main deck. Only one hose line is provided for deck fire fighting. This hose line can reach cargo transfer stations #7 and #8.

Aboard the Taluga, cargo transfer stations 5 and 6 cannot be reached with foam without the addition of 50 ft of hose to the foam hose line. This additional 1 1/2 inch hose is not readily available aboard the ship and, as a consequence, fires in the area of these stations could not readily be attacked with foam.

Both pump rooms on the Taluga are provided with carbon dioxide (CO_2) flooding systems. Both systems are designed

TABLE 2-4

TALUGA FIRE PROTECTION SYSTEMS

FIRE PROTECTION TYPE	LOCATIONS	TYPE	CAPACITY	COMMENT
Fire Water Pumps	Engine room	Electric centrifugal	400 gpm at 125 psi	Main fire water pumps
	Engine room	Electric centrifugal	450 gpm at 125 psi	Main fire water pumps
	Engine room	Steam centrifugal	450 gpm at 449 psi	Standby fire and tank cleaning
	Engine room	Steam Positive Displacement	400 gpm at 26 psi	Standby fire water and general service pump
	Forward	Diesel Centrifugal	1000 gpm at 123 psi	Standby fire water -must be manually started at pump
	Forward	Steam positive displacement	275 gpm at 200 psi	Standby-fire water/bilge pump
Foam	Helipad	1-1 1/2 AFFF handline	50 gal conc + 50 standby	Hose set up for helipad only
	Repair	1-1 1/2 AFFF handline	50 gal conc + 50 standby	Hose can reach forward two fuel transfer stations
	Aft	5 discharge stations	100 gal conc + 100 gal standby	Four foam stations below deck one station at deck level,deck hose will reach aft fuel station

TABLE 2-4
(Continued)

TALUGA FIRE PROTECTION SYSTEMS

FIRE PROTECTION TYPE	LOCATIONS	TYPE	CAPACITY	COMMENT
CO_2	Pump room	Inerting	-	Actuate at main deck door to respective compartment
	Pump ro .	Inerting	-	
	Repair locker	Hand portable	- -	Fight small electrical fires
Dry Chemical	Helipad	Stationary hose line discharge Purple K	350 lbs with 50 ft of hose	Fight fire up to about 500 sq ft in area
	Repair locker Aft & Midship			
	Repair locker	Hand portable Purple K	30 lb	Fight small spill-fire

for manual actuation from the access door to each pump room. Carbon dioxide can both extinguish a fire and prevent ignition of liquid and gaseous hydrocarbon releases. Carbon dioxide is an asphixant; thus, personnel must either be cleared from the pump room before the CO_2 systems are actuated or personnel must be provided emergency air packs. The latter is provided aboard the Taluga. The cargo pump rooms on the Taluga are equipped with fusible plug fire detection. These detectors are capable of actuating alarms on the bridge.

The dry chemical handline units aboard the Taluga can be used to extinguish liquid spill fires on the deck of up to 400 sq ft. The dry chemical units are very effective in fighting fires in conjunction with foam. The foam can be used to knock down the majority of the fire and the dry chemical used to extinguish small residual fires not extinguished by the foam.

2.2.4 Fire Fighting Systems - USNS Sealift Atlantic

The fire water distribution system aboard the Sealift Atlantic is nearly identical to that aboard the Taluga, see Table 2-5. The foam system; however, is much more extensive on the Sealift Atlantic. The Sealift Atlantic has a dedicated foam solution piping system that supplies foam solution (water plus concentrate) to handlines and monitor nozzles located along the deck. The location of foam monitor nozzles and handlines on the deck are shown in Figure 2-5. The foam monitor nozzles are designed to provide 0.016 gpm/ft^2 of foam to the cargo tank deck area. The cargo pump room is provided with a fixed foam sprinkler system.

The A0177 Class Navy tanker is presently under construction. This class tanker will be provided with a fixed foam sprinkler system over the entire cargo tank area. The foam system will be designed to deliver 0.16 GPM/ft^2 of foam to the cargo deck. A foam application rate of 0.16 GPM/ft^2 is required to extinguish and secure a typical hydrocarbon spill fire. Where foam sprinkler systems are used to protect a potential spill fire area, the sprinkler system should be designed to deliver 0.16 GPM/ft^2. Monitor nozzles deliver large quantities of foam to a small deck area very rapidly. As portions of the fire are extinguished, the foam delivery location can be altered and the fire progressively extinguished. Tests have shown that a monitor nozzle foam system designed to deliver 0.016 GPM of foam per square foot of total cargo deck area is adequate to fight typical deck fires.

All commercial tankers with Coast Guard approval are required to have a full deck foam protection system using

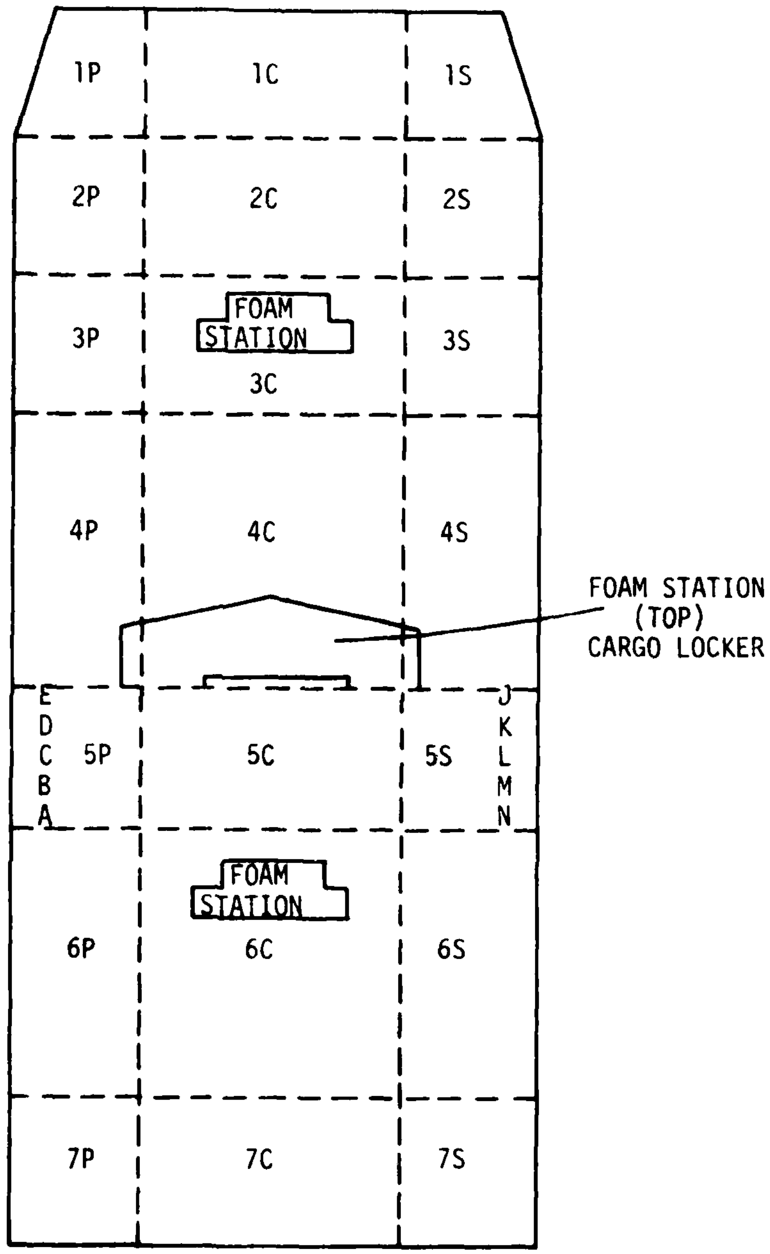


FIGURE 2-5. SEALIFT TANK AND FOAM STATION CONFIGURATION

TABLE 2-5

FIRE FIGHTING SYSTEMS ABOARD SEALIFT ATLANTIC

FIRE PROTECTION TYPE	LOCATIONS	TYPE	CAPACITY	COMMENT
Fire Water Pumps	Engine room	Electric powered centrifugal	450 gpm at 129 psi	Fire, bilge and ballast pump
	Shaft alley	Electric powered centrifugal	850 at 240 ft of head	Fire and foam pump
Foam				
Monitor Nozzle	At foam station	National PC-100	800 gpm at 100 psi	Fight large deck fires
Handlines	see Figure 2-5	-	-	Fight small deck fires

either monitor nozzles or fixed sprinkler systems to deliver foam. Most operators have elected to use monitor nozzles. This regulation is fairly new and considerable retrofit is in progress.

2.3 IMODCO - SPM

The SPM for the proposed application is being designed by IMODCO. In the event of a cargo spill on the SPM some fuel could be held in a drainage channel. The channel dimensions are 68 inches O.D. by 24 inches I.D. by 12 inches deep. The channel is drained by two 3-inch diameter pipes. In the event of a fire on the SPM, gaskets in the rotating seals and at piping flanges could be damaged.

2.4 Code Requirements

Tanker construction and fire protection requirements are stipulated by a number of governmental and concensus code organizations around the world. Key codes have been reviewed to determine the type of fire protection required aboard tankers and at SPM facilities. Additionally, we have reviewed standard industry practices for fire protection aboard tankers and at SPMs.

2.4.1 U. S. Coast Guard Regulations

Fire protection requirements for tankers as stipulated by the U. S. Coast Guard have evolved over the years to reflect tanker service experience, the increased sizes of tankers and new fire/hazard control systems for tankers. Most of these new regulations are retroactive to tankers greater than 20,000 DWT. The present Coast Guard tanker regulations reflect present day thinking of many regulators.

Coast Guard regulations for fire fighting equipment to be on board tankers are contained in 46 CFR "Shipping" Subchapter D Part 34. The Coast Guard also approves, pursuant to performance testing, fire and safety related appliances acceptable for use aboard Coast Guard approved vessels. The approved equipment list is published as Department of Transportation Coast Guard "Equipment List" Items Approved Certified or Accepted under Marine Inspection and Navigation Laws-No. CG-190. In addition to these documents, the Coast Guard also prepares design manuals that describe procedures for quantifying required fire protection requirements. As a part of this study, we have had a number of conversations

with Coast Guard personnel to assist us in understanding their present thinking.

The Coast Guard requires that fire water be supplied to ship fire water piping via at least two independent pumps (primary and backup). The pumps must be adequately separated so that an accident damaging one pump does not easily damage the other. Along the main deck of a tanker, fire water piping and hose lines must be located so that every point on the deck can be reached with two hose lines. These two hose lines must be supplied water from **independent** fire water main outlets. One of the hose lines must be 50 feet in length. Each fire water pump should be capable of supplying at least two 2 1/2-inch fire water lines (about 470 gpm total water flow). There are other fire water requirements for a tanker that usually dictate fire water capabilities in excess of 470 gpm. The fire water headers must be provided block valves so that a portion of the fire water main can be out of service for repairs without shutting down the entire fire water system.

Tankers are required to have low expansion foam fire fighting systems to fight cargo fires on the main deck (deck where cargo piping is located). The foam system may be either a fixed sprinkler type of a monitor nozzle system. As previously discussed in this section, a fixed foam sprinkler system must be capable of delivering 0.16 GPM/ft^2 of deck area protected by that system while a monitor nozzle system needs to provide area while the monitor nozzle system needs to provide 0.016 GPM/ft^2 of total deck area. This difference is permitted based on the maneuverability of monitor nozzles combined with the fire fighting effectiveness of foams.

The Coast Guard will accept only approved foam production equipment and foam concentrate. At this time, the Navy uses Aqueous Film Forming Foams (AFFF) aboard its ships. Present commercial formulations of this foam have not passed Coast Guard fire test requirements; thus, no AFFF foams are on the Coast Guard's approved equipment list.

The Coast Guard requires that cargo pump rooms be provided with either a gas inerting or a fixed sprinkler foam fire fighting system. Historically, carbon dioxide has been used for inerting systems aboard ships; although, Halon agents are now being used for some shipboard areas.

The Coast Guard has recently announced a new regulation stipulating that all new tankers greater than 20,000 DWT and all existing product tankers greater than 20,000 DWT that

have high capacity tank washing machines be outfitted with cargo tank gas inerting systems. On typical tankers, the cargo tanks are open through the cargo tank vent mast to the atmosphere. When the cargo tanks are being filled, vapors are generated and released from the tank vent. When the cargo tanks are being emptied, air is drawn into the tank to maintain the tanks at atmospheric pressure; thereby, preventing collapse of the tank. During both the loading and off-loading operations, the vapor space in each cargo tank passes through both the lower and upper explosive limits. Flame arrestors are provided on air vents to prevent propagation of flames from external sources to the cargo tanks. However, even with these flame arrestors a number of tankers have experienced explosions. As a consequence, the Coast Guard is now requiring cargo tank gas inerting systems on both crude oil and product tankers.

2.4.2 American Bureau of Shipping (ABS)

Many of the tanker fire fighting requirements set forth by the ABS are similar to those promulgated by the Coast Guard. ABS requires that there be at least two independent fire water pumps and each pump must be able to supply a minimum of 2 fire streams determined by the nozzles to be used. As with the Coast Guard regulations, the actual water flow requirements are based on vessel size; thus, in practice, the actual design minimum water requirement is well above the 2 fire stream minimum for tankers.

The fire main hydrants and block valve requirements are identical to the Coast Guard's. The ABS stipulates that there must be a fire hose connection with hose in place for every one hundred feet of ship length.

ABS requires that tanker decks be provided with fixed foam fire fighting systems. For all practical purposes, the ABS foam application rates for tanker deck fire fighting systems are identical to the Coast Guard's. The ABS requires that adequate foam concentrate be provided to allow 30 minutes of foam system operation.

Cargo pump rooms must be provided with a fixed pipe fire fighting system. The fire fighting system must be operable from the deck. The fire fighting system can be CO_2, halon, fire water, foam or steam subject to approval of ABS. At this writing, inert gas systems are not required for cargo storage tanks.

2.4.3 Inter-Governmental Maritime Consultative Organization (IMCO)

IMCO code making utilizes representatives from maritime regulation bodies throughout the world and representatives from ship operating organizations. The thrust of IMCO is to develop reasonably uniform standards for shipping in all areas of the world. The U. S. Coast Guard and ABS participate in the IMCO code making process.

ABS and the Coast Guard generally adopt most of the IMCO regulations for providing fire protection aboard tankers. The only significant difference is that IMCO does not require inert gas systems for cargo tanks on ships of less than 100,000 DWT.

2.4.4 Single Point Mooring (SPM) and Hoses

Regulations for SPM fire protection are listed in the ABS document "Rules for Building and Classing Single Point Moorings - 1975." This document suggests that unmanned SPM's handling flammable fluids be provided with either 9 lb (2 1/2 gallons) of foam or an equivalent class B extinguisher (15 lbs carbon dioxide or 10 lbs dry chemical).

The Oil Companies International Marine Forum "Buoy Mooring Forum Hose Guide" describes transfer hose inspection testing and inspection frequency. This body recommends that hoses be removed from service and subjected to extensive tests every six months and if the hoses are subjected to heavy weather, it is recommended that inspections be conducted every 3 months.

The following is reproduced from this document:

> 4.3 Hose Testing and Inspection
> 4.3.1 Pressure testing of the hose strings should be performed every three to six months depending upon environmental conditions at the buoy site. Testing after a very severe period of bad weather should be considered. Present or future governmental regulations may also require periodic testing. This test should consist of raising the internal pressure in the hose to its rated pressure or maximum operating pressure plus 50%, whichever is lower, preferably with water, and holding this pressure for a period of three hours. A visual inspection of all hose should be commenced after the pressure has stabilized. The visual inspection shall be as outlined in Section 4.0.

4.3.2 Testing as outlined below will be dependent upon the results of in situ and visual testing and inspection. However, as a minimum, it is suggested that all hoses be taken out of service and tested and inspected in accordance with the following criteria. (The frequency of testing will be dependent on time or throughput whichever occurs first and environmental conditions at the site).

TIME CRITERIA

Type of Hose	Recommended Period of Time
Floating	1/2 years
Submarine	1/2 years
Underbuoy	midway between buoy drydocking period - maximum of 3 years
Tanker Rail	6 months-1 year
First Off the Buoy	6 months-1 year

THROUGHPUT CRITERIA

Hose Nominal Inside Diameter inches	(mm)	Throughput (Millions) Barrels	Cubic Meters
30	(750)	225	36
24	(600)	150	24
20	(500)	100	16
16	(400)	75	12
12	(300)	50	8

4.3.3 Hydrostatic Test

4.3.3.1 Each hose shall be tested with water to pressure rating of the hose being tested. The procedure shall be as follows:

(a) Lay out the hose as straight as possible on supports that permit the hose to elongate freely.

(b) Fill with water, venting to remove all air and apply a pressure of 0.7 Bar (10 psi).

(c) Measure the overall length of the hose assembly.

(d) Increase the pressure over a period of 5 minutes, from 0·7 Bar (10 psi) to one half of the rated pressure; hold this pressure 10 minutes, then reduce the pressure over a period of 5 minutes to zero.

(e) Raise the pressure over a period of 5 minutes to rated pressure and hold for 10 minutes.

(f) Before releasing the full test pressure, measure the overall length of the hose assembly to ascertain the temporary elongation and record the increase as percentage of the original length measured at 0·7 Bar (10 psi).

(g) Reduce the pressure over a period of 5 minutes to zero.

(h) After an interval of at least 15 minutes raise the pressure again to 0·7 Bar (10 psi).

(i) Measure the overall length of the hose assembly to ascertain the permanent elongation; record the increase as a percentage of the original length measured at 0·7 Bar (10 psi).

Test records should be kept of each hose so that the temporary elongation under pressure can be compared to the original test and subsequent routine tests. Discussions on suitable forms are noted in Paragraph 5.0.

When the field test temporary or permanent elongation of a hose exceeds the factory test temporary or permanent elongation respectively by 2% of the overall length, the hose should be retired from service.

4.3.4 Electrical Continuity Test

This test should be carried out on all hose removed from service for hydrostatic pressure tests.

For electrically bonded hose, continuity should exist during and after the hydraulic test. (See SPM Forum Hose Standards, Part A.6.1.3). For electrically discontinuous hose. The resistance between the end nipples of each length of hose shall be not less than 100,000 ohms.

4.3.5 Vacuum Test

This test should be carried out on hose removed from service for hydrostatic pressure tests.

Seal off both ends with transparent plexiglass plates of sufficient strength, using putty as a sealant or bolt up using a soft rubber gasket. One plate shall be fixed for connection to a vacuum source. Lay a flashlight in this end with its beam directed toward the opposite end. An inspection mirror using sunlight may also be manipulated from outside the plates to provide a proper light source.

Apply a vacuum of at least--510 millibar gauge (15 inches of mercury) and preferably--680 millibar gauge (20 inches of mercury) for a period of 10 minutes.

Inspect the interior of the hose for blisters or bulges. Blisters, bulges or separation of tube from carcass is reason to retire hose from service. Any tear, cut or gouge through the tube is reason to retire hose from service.

4.3.6 External Inspection

4.3.6.1 Covers

The rubber cover on the hose serves the primary function of protecting the reinforcement or the flotation material of the hose from damage. The cover should be cleaned and carefully examined to detect areas wherein reinforcement or flotation damage may have occurred. Inspect hose cover for cuts, gouges, tears and abraded spots.

Any cuts, gouges or tears down to or through the cover breaker, but not into the outer reinforcement, should be repaired before hose is returned to service. Hose repair kits and repair instructions are available from hose manufacturers and should be provided with all new installations.

If reinforcement or flotation material is exposed, determine extent of damage by visual

inspection at rest and under pressure. If damage is minor, repair and return to service. If damage is extensive, retire from service.

Covers may show surface cracking or crazing due to prolonged exposure to sunlight or to ozone. Such deterioration, which does not expose reinforcing or flotation material, is not cause for retirement. Localized areas of oil-softened rubber are cause for retirement.

4.3.6.2 Carcass

Look for crushed or kinked spots or broken reinforcement as evidence by any permanent distortion, longitudinal ridges or bulges. Hoses showing such defects shall be removed from service. Bulgest areas shall be marked and examined again under pressure. If they become hard, indicating leaking tube or ruptured reinforcement, the hose shall be retired from service.

4.3.6.3 Fittings

Exposed surfaces of couplings, flanges and nipples shall be examined for cracks or excessive corrosion. Either condition shall cause the hose to be retired from service.

4.3.7 Internal Inspection

Wipe the inside of the couplings and nipples clean with a rag and examine with flashlight for cracks or excessive corrosion. Cracks or excessive corrosion shall cause the hose to be retired from service. Inspection shall be made of the interior for blisters, bulges or separation of tube from carcass. Any of the foregoing defects plus any tear, cut or gouge in the tube shall be cause for removal of the hose from service. For hose of sufficiently large bore, it is recommended that a man physically examine the full-length interior of the hose for soft spots. Any evidence of soft spots should result in the retirement of the hose from service. Appropriate safety precautions should be taken while conducting this inspection.

2.4.5 Code Summary

The analysis of codes for tankers show that the following fire fighting systems should be provided for cargo fire fighting:

1. A fire water system provided water by two independent fire water pumps.
2. A main deck (deck where cargo piping system is located) fire water system. Fire water hoses must be located on the deck so that every point on the deck can be reached with two independent fire water streams.
3. The main deck should be provided with a fire fighting foam system capable of applying foam to any point on the deck.
4. The cargo pump rooms must be provided with a fixed fire fighting system.
5. Some codes are requiring gas inerting systems for cargo tanks.
6. Transfer hoses must be inspected on a regular bases to minimize the potential for hose failures.

SECTION 3

BACKGROUND FOR FAULT TREE AND SPILL PROBABILITY METHODOLOGIES

One of the primary tasks of this study is the analysis of the fuel spills and associated fires that may result from operation of the offshore bulk fuel storage system. In order to approach this task in a quantitative fashion, a system safety analysis method known as fault tree analysis was used.

3.1 Fault Tree Methodology

Fault trees provide a powerful technique for describing overall system reliability and safety. The fault tree is a graphical representation of the logic associated with the development of a particular system failure state from the original component primary failure events.

Fault tree analysis was originated to study unlikely events, events which may lead to an undesirable system failure. It is important to recognize, however, that only one failure state is normally analyzed in a single fault tree.

Once an undesired event is selected for system failure analysis, it becomes the top event on the fault tree. Second level events which must simultaneously fail in order to cause the top event are connected by an AND gate. Multiple events which individually may cause the top event are connected with an OR gate. Boolean algebraic expressions are used to express the manner in which individual component failure probabilities are related to the total system failure probabilities.

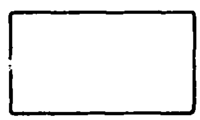
Therefore, a fault tree is really a logic diagram that traces all failure modes and combinations of failure states that can lead to the top undesired event. The group of symbols for the Boolean operations, depicted in Figure 3-1, are frequently called gates to indicate passage from one level of event to the next higher event. The real strength of the fault tree symbolism lies in the fact that the symbols can be readily translated into algebraic terms. Hence, the overall failure probability of the top event can be easily obtained for each failure sequence once the failure rates of

FIGURE 3-1

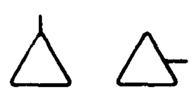
FAULT TREE SYMBOLISM

Event Representations

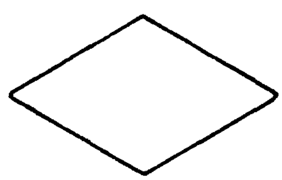
The rectangle identifies an event that results from the combination of fault events through the input logic gate.



The triangles are used as transfer symbols. A line from the apex of the triangle indicates a transfer in and a line from the side denotes a transfer out.

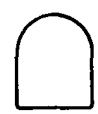


The diamond describes a fault event that is considered basic in a given fault tree. The possible causes of the event are not developed further because the event is of insufficient consequence or the necessary information is availble.

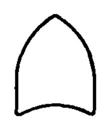


Logic Operations

AND gate describes the logical operations whereby the coexistence of all input events is required to produce the output event.



OR gate defines the situation whereby the output event will exist if one or more of the input events exists.



all primary events are available. Figure 3-2 illustrates the algebraic combinations of probabilities from a fault tree analysis.

In the particular case of the Offshore Bulk Fuel System, the failure state is a cargo fuel spill. The fault trees are used to evaluate the probability of cargo fuel spills during different ship operational modes. An undesired, hazardous event such as a spill of volume greater than 10^5 gallons is selected and the probability of this event is determined by evaluating the probabilities of man/machine failures which either singly or in combination can cause the event to occur.

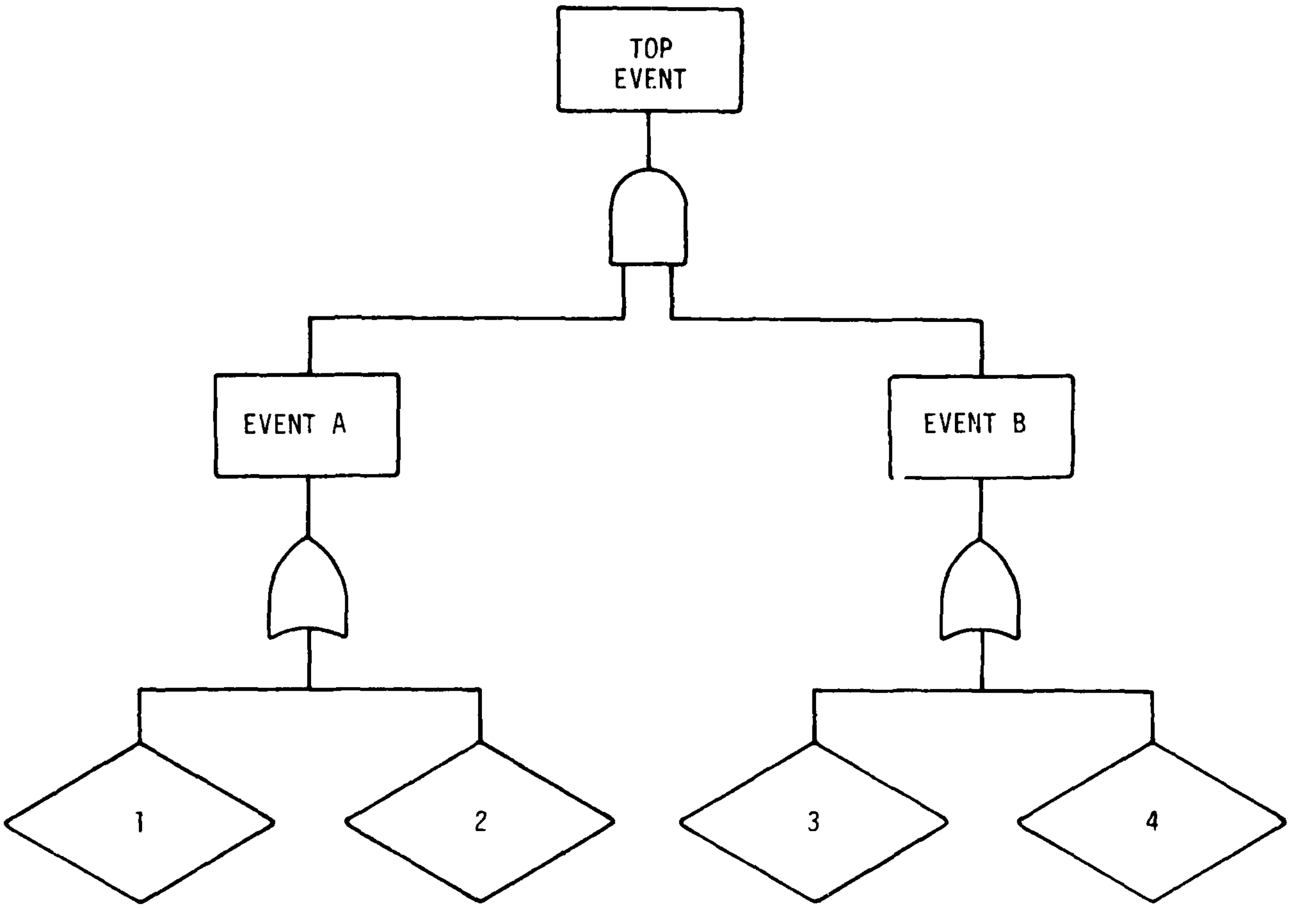
The example of a fault tree given in Figure 3-2 is often adequate for describing simple systems, but is inadequate for understanding the operations and potential hazards of the Offshore Bulk Fuel System tanker. The first difference is that Figure 3-2 uses mutually exclusive events. The statement

$$P_A = P_1 + P_2$$

implies that 1 and 2 are mutually exclusive events. An example is a circuit component which has a total failure probability which is the sum of the probabilities of two mutually exclusive failure modes - short and open. The existence of one precludes the other.

In the majority of the fault trees in this study, the causes of failure are independent but by no means mutually exclusive. For example in Figure 4-1 (see next section), Ship Offloading-Manual Detection without Patrol and Manual Shutdown, there are eleven independent failure modes each of which is capable of causing a 1000 to 10,000 gallon spill. One failure mode does not preclude the occurrence of any or all of the others during any operating period.

The fact that any combination of eleven failures will produce a spill of 1000 to 10,000 gallons introduces a computational difficulty which is solved by the use of complimentary space. Rather than calculate the probability of various combinations of failures that can occur, the probability that no spill occurs is calculated and subtracted from unity (1.0) to yield the probability of at least one failure causing a spill during a defined operating period. The binomial expansion below illustrates this computational method for a failure event that can be caused by any one of four failure modes.



$$P_A = P_1 + P_2 \qquad P_B = P_3 + P_4$$

$$P_{TOP} = P_A \, P_B = (P_1 + P_2)(P_3 + P_4)$$

FIGURE 3-2. TYPICAL FAULT TREE ILLUSTRATION OF COMPONENT PROBABILITY RELATIONSHIPS

$$(P + Q)^4 = 1$$

$$P^4 + \frac{4!P^3Q}{3!1!} + \frac{4!P^2Q^2}{2!2!} + \frac{4!PQ^3}{1!3!} + Q^4 = 1$$

where P = probability of success
Q = probability of failure

The probability of one or more failures is simply:

$$P(1 \text{ or more failures}) = 1 - P(\text{no failures}) = 1 - P^4$$

The use of complimentary space is made doubly important by the fact that, in general, the individual failure modes do not have equal probabilities even when using a conservative data base as in this report.

Table 3-1 provides a listing of the failure modes and associated failure probabilities to be used in illustrating the calculation of end event probabilities for the fault trees. For illustrative purposes we will refer to Figure 4-1. For the purpose of this discussion we will adopt the following notation:

B - spill event $< 10^3$ gallons
C - spill event $10^3 - 10^4$ gallons
D - spill event $10^4 - 10^5$ gallons
E - spill event $> 10^5$ gallons
F_1 - event Manual Shutdown Normal
G_1 - event Manual Shutdown Fails

Since F_1 and G_1 are mutually exclusive events, then:

$$P(F_1 + G_1) = P(F_1) + P(G_1) - P(F_1G_1)$$
$$= P(F_1) + P(G_1)$$

Therefore, for spill event B, a spill of $<10^3$ gallons;

$$P(B) = P(F_1 + G_1)(1 - R_T)$$
$$= .5041$$

TABLE 3-1

FAILURE MODES AND PROBABILITIES

FAILURE MODE	SYMBOL ($_i$)	RELIABILITY R_i	PROBABILITY OF FAILURE Q_i
1" x 1/16" Weld Leak	K	.9974	.0026
1" x 1/16" Gasket Failure	L	.3493	.6507
Small Valve Packing Leak	M	.5910	.4090
8" x 1/16" Weld Leak	N	.99912	.00088
Major Gasket Failure	O	.8103	.1897
Major Valve Packing Leak	P	.9002	.0998
Total Gasket Failure	Q	.9002	.0998
Small Pipe Failure	R	.99997	.00003
Single Transfer Pipe Failure With One Pump	S'	.999996	.000004
Single Transfer Line Failure With Three Pumps	S"	.9999992	.0000008
Two Transfer Pipes Fail With Two Pumps	S2'	.99999996	.00000004
Two Transfer Pipes Fail With One and Three Pumps	S2"	.999999992	.000000008
1/8" Diameter Hose Leak	T	.4959	.5041
1/2" Diameter Hose Leak	U	.5910	.4090
Single Hose Failure With One Pump	V'	.7554	.2446
Single Hose Failure With Three Pumps	V"	.9323	.0677
Two Hoses Fail With Two Pumps	V2'	.9999	.0001
Two Hoses Fail With One and Three Pumps	V2"	.9999	.0001

It is important to note that the meaning is that there is a probability of 0.5041 of at least one spill of less than 1000 gallon magnitude during one year (8766 hours) of continuous pumping operations. The probability of "at least one spill" should not be confused with the "expected number of spills." In all fault trees the probability of "at least one spill" is less than 1.0, while the "expected number of spills" can be greater than 1.0

There are three sub-branches in this part of the fault tree that leads to the 10^3 - 10^4 gallon spill event C. Let us denote the left, center, and right branches as C_1, C_2, and C_3, respectively. Since anyone or all of four failure modes in branch C_1 can cause a 10^3 - 10^4 gallon spill, a non-spill condition is only achieved if none of them occur. The probability of at least one spill can be determined by calculating the probability of no spills and subtracting this value from 1.0. Let the reliability of an individual unit be denoted by R_i. Since the probability that the unit does not fail is equivalent to its reliability, then the probability of no spill can be calculated by multiplying the individual unit reliabilities together. Since either "Manual Shutdown Normal"or "Manual Shutdown Delay" achieve the same spill magnitude, the probability of spill caused by this branch of the tree can be computed as follows:

$$P(C_1) = P(F_1 + G_1)(1 - R_K \cdot R_L \cdot R_M \cdot R_U)$$

$$= (1.0)[1 - (.9974)(.3493)(.5910)(.5910)]$$
$$= 1 - .1217$$
$$= .8783$$

The center branch, C_2, requires no new computation concepts, but it does have different failure modes with higher leak volumes.

$$P(C_2) = P(F_1 + G_1)[1 - R_O \cdot R_P \cdot R_N]$$

$$= (1.0)[1 - (.8103)(.9002)(.9991)]$$
$$= 1 - .7288$$
$$= .2712$$

The right branch requires three new concepts. The first is a delay in shutdown time causing a set of failure modes to yield a different spill magnitude. This branch is

also the left hand branch of the 10^4 - 10^5 gallon event with a different shutdown time

Branch C_3 is the first example of part-time equipment operating configurations affecting the time of operation of individual equipment in the reliability calculations. It is not clear at this time whether one cargo pump can maintain the required cargo transfer rate. A decision was made to allocate 80% of cargo transfer time based on a single cargo pump operating and 20% to the three pump mode of operation.

The third concept is that of simultaneous failure of either both cargo transfer pipes on ship deck or both cargo transfer hoses from the ship to the SPM. Simultaneous failure is unlikely, but a possible event. This type failure will usually be the result of external events such as heavy wave action or tidal waves. It is important to recognize that simultaneous failures are considered in the fault tree. The probability of spill due to a failure mode in the right branch, C_3, can be computed as follows:

$$P(C_3) = P(F_1)(1 - R'_V R'_S R'_{V2} R'_{S2})$$
$$= (.986)[1 - (.7554)(1.0)(.9999)(1.0)]$$
$$= (.986)(1 - .7553)$$
$$= .2413$$

Now that the three branches have been evaluated we can determine P(C), the probability of a spill volume of 10^3 - 10^4 gallons by the following calculations:

$$P(C) = P(C_1) + P(C_2) + P(C_3) - P(C_1C_2) - P(C_1C_3) - P(C_2C_3) + P(C_1C_2C_3)$$
$$= .8783 + .2712 + .2413 - (.8783)(.2712) - (.8783)(.2413) - (.2712)(.2413) + (.8783)(.2712)(.2413)$$
$$= .9328$$

The value of .9328 is the probability of at least one spill of 10^3 - 10^4 gallons during one year of continuous pumping through two hoses to an SPM in a system featuring manual detection patrol and manual shutdown.

It is important to note that .9328 is the probability of "at least one spill." It does not mean that additional spills cannot occur.

These calculations indicate that for this operating configuration the chances of spills in the 1000 - 10,000 gallon range are quite high.

The next part of the fault tree examines the probability of spill event D. Notice that there are two sub-branches leading to this event. We will notationally refer to the left hand branch as D_1 and the right hand branch as D_2. The probability of realization of the left hand branch is:

$$P(D_1) = P(G_1)(1 - R_V' \cdot R_S' \cdot R_{S2}' \cdot R_{V2}')$$
$$= (.014)[1 - (.7554)(1.0)(.9999)(1.0)]$$
$$= .0034$$

The right hand branch D_2 is the first example of failure probabilities computed using the 20% duty cycle for additional pump requirements.

$$P(D_2) = P(F_1)[1 - R_Q \cdot R_S'' \cdot R_V'' \cdot R_{S2}'' \cdot R_{V2}'']$$
$$= (.986)[1 - (.9002)(1.0)(.9323)(1.0)(1.0)]$$
$$= (.986)(1 - .8393)$$
$$= .1585$$

Now the probability of D can be computed in the following manner:

$$P(D) = P(D_1) + P(D_2) - P(D_1 D_2)$$
$$= .0034 + .1585 - .0005$$
$$= .1614$$

The only conditions under which the spill event E can occur is when a delay in normal shutdown occurs.

$$P(E) = P(F_1)[1 - R_Q \cdot R_S'' \cdot R_V'' \cdot R_{S2}'' \cdot R_{V2}'']$$
$$= .0014[1 - (.9002)(1.0)(.9323)(1.0)(1.0)]$$
$$= .0014(1 - .8393)$$
$$= .0002$$

The remaining fault trees present no new conceptual or computational difficulties. The probabilities of the

several spill magnitudes are discussed for the various operating modes and design alternatives in Section 4.

3.1.1 Effect of Equipment Use Life

The basic assumption is that the ship must meet the required delivery rate to the beach 24 hours/day for a period of one year. The reliabilities and complementary probabilities of failure are computed on the assumption of 8766 hours of operation per year. An example of this assumption is a 1" x 1/16" weld leak. As a matter of engineering judgment and analysis of the piping diagrams, it was estimated that there are approximately 100 welds which have the potential for failures during pumping operations. The failure rate for a minor weld leak was set at $.003/10^6$ hrs based on an analysis of WASH 1400 (26) and other authoritative reports. The reliability (and probability of failure) can be determined in the following manner:

$$n = 100$$
$$\lambda = .003/10^6$$
$$t = 8766 \text{ hrs}$$
$$n\lambda t = .00263$$

Reliability

$$R = e^{-n\lambda t}$$
$$R = e^{-.00263}$$
$$R = .9974$$

Probability of Failure

$$Q = 1 - R$$
$$= 1 - .9974$$
$$= .0026$$

This computational method and assumption of 8766 operating hours is used throughout this report. A significant exception with major impact on spill probabilities is the operating time of the hoses. Due to the much greater pumping rate of the tankers used in resupplying the moored tanker, the number of hoses required for tanker loading on an annual basis is set at 0.5 rather than the 2.0 required for continuous pumping to the SPM.

A similar adjustment is made for gaskets and valves required in the loading mode of operation. The offloading mode assumes 40 gaskets and 20 valves are required for 8766 hours per year. Loading mode is assumed to require the continuous use of 20 gaskets and 10 valves. A similar

argument could be made for piping, but the failure rates are so low that any adjustment is meaningless by several orders of magnitude.

Subsequent to the performance of these calculations, we have been advised by CEL that the OBFS pumping operations will be on a ten hour on, two hour down basis for an operating period of 180 days. This will result in a considerble reduction in operating hours as compared to the 8766 hours of continuous operations which served as the base case in this report. This reduction in operating hours would ordinarily have a significant effect upon the failure probabilities of components in the system. However, this condition is not likely to hold for this case because of the additional start up and shutdown cycles that are imposed by the ten hour on, two hour down operating cycle.

The hoses that are used in the OBFS system are likely to be more adversely affected by the start up and shutdown transients than by increased hours of operation.

Considerable evaluation and modification of the failure probabilities would be required to reflect this change in operating cycle conditions. A method would have to be developed to accurately consider the effect of the combination of demand type failures and continuous operating time failures.

Preliminary analysis of this situation indicates that the available failure data is not structured in such a way as to make a recalculation of these failure probabilities meaningful. Accordingly, the failure probabilities developed under the assumption of 8766 hours of continuous operation are probably reasonably good estimates of the values that would result from the new operating conditions. More importantly, it does not appear that the basic conclusions and recommendations made in this report would be altered in any way.

SECTION 4

OFFSHORE BULK FUEL SYSTEM SPILL ANALYSIS

In order to quantify the magnitude of spills that may occur in connection with operation of the bulk storage tanker, an analysis of component failure modes was conducted. These failures were translated into spill rates using principles of fluid mechanics. Estimates of spill times were made by considering spill detection methods and the time required for spill isolation. This information was then combined to produce the estimated spill volumes that result from these component failures.

4.1 Failure Mode Analysis

The component failure modes were combined into a system failure study using the method of Fault Tree Analysis. This method is a graphical presentation of interrelationships of the individual equipment failure events that lead to the critical end events which are in this case spill volumes.

The individual component failures that were examined are those that experience with fuel transfer systems and analysis of the operational mode proposed for the storage tanker indicated are reasonable failures to consider. These failures range from a small hose leak, defined as a 1/8-inch diameter hole, to a breach in the integrity of a single cargo tank. These failures and the resulting leak rates are given in Table 4-1.

The normal mode of operation for the storage tanker is considered to be when it is moored at the SPM and supplying fuel to the beach via the connecting hoses to the SPM and the underwater pipelines. This is referred to in this report as the tanker OFFLOADING condition.

Another operational situation that will occur regularly is the resupply of the storage tanker by a supply tanker. This is referred to in this report as the tanker LOADING condition.

The location of spills that can occur under these operating conditions is important in selection and design of spill detection and isolation equipment. In general, these

TABLE 4-1

FAILURE MODES AND ASSOCIATED LEAK RATES

FAILURE MODE	LEAK RATE	REMARKS
1/8" diameter hose or weld leak	2 gpm	
1" by 1/16" weld leak	9 gpm	
1" by 1/16" gasket failure	9 gpm	
Small valve packing leak	9 gpm	
1/2" diameter hose leak	27 gpm	
Major gasket failure	65 gpm	
Major valve packing leak	65 gpm	
8" by 1/16" weld leak	68 gpm	
Single hose or transfer line failure	1000 gpm	1 centrifugal pump supplying flow
Total gasket failure	260 gpm	
Two hoses or transfer line failures	2000 gpm	1 centrifugal pump per hose
Small pipe fails	500 gpm	Cargo pump recirc. line
Single hose or transfer line fails	3000 gpm	3 centrifugal pumps supplying flow
Two hoses or transfer lines fail	4000 gpm	3 centrifugal pumps supplying one hose and 1 positive displacement pump supplying one hose

spills can occur on the deck, in the pump room, on the SPM, and on the water adjacent to the ship(s) and the SPM.

All spill volumes referred to in this report in connection with the failure mode analysis are predicated upon the storage tanker being the USNS Taluga which was used as the reference ship in this part of the study. If one of the Sealift class tankers is considered, then the analysis is still valid for the small rate spills. Spills of this type are produced by failures such as hose, gasket, weld, and valve packing leaks. Leak rates from these events are determined by the fuel system operating pressure and the effective orifice size and will, therefore, not be significantly different for the Sealift class. The principle differences can be expected for the large rate spills because of the larger fuel system piping, fourteen (14) inch lines, and larger capacity cargo pumps, 4200 gpm, on the Sealift class.

4.2 Determination of Spill Volumes

The estimated spill volumes depend upon the tanker operational mode, the type of individual component failure, the location of the spill and spill detection time. The spill detection time will be directly influenced by the type of spill detection method utilized. Estimates must be obtained for the spill times for spills of each type. These can then be combined with the previously described spill rates to obtain estimates of the spill volumes that may be encountered during operation of the bulk fuel storage system.

4.2.1 Offloading

First, we will examine tanker OFFLOADING under the condition that spill detection and isolation is a completely manual operation. In this case, it was assumed that the watch stations that are manned are the bridge, a pump room, and the engine room. The expected time to detect a small rate spill, i.e., a leak rate <260 gpm, was evaluated to be approximately two (2) hours. This comes from the assumption that each watch is four hours and that detection of the small rate spill can occur only at the change of the watch. A reasonable approach to take for this situation is to model the time from the initiation of the spill to the time that the spill is detected as a random variable having a uniform distribution between zero and four hours. This yields an expected time to detect small rate spills of approximately

two hours. The time to communicate spill detection and to stop the fuel flow is negligible compared to the two hour detection time.

On the other hand, large rate spills (1000 gpm or greater) are likely to be detected by the pump room watch observing changes in pump discharge pressure. In this case, the expected time to detect that a spill is occurring is approximately one (1) minute.

When spill detection has occurred, shutdown time is estimated to be approximately three (3) minutes. This value accounts for the time required for the pump room watch to communicate with the other watch stations and to manually close a ten inch valve in a pressurized fuel transfer system. The combination of these values yields a total expected spill time of four (4) minutes.

The estimated spill times are used with the appropriate spill rates to calculate the spill volumes that are shown on the fault tree in Figure 4-1. A general examination of Figure 4-1 indicates that the time to detect a small rate spill contributes significantly to the spill size.

The probability of occurrence of each spill category has been summarized for each fault tree in Table 4-2. From the information in this table, we can see that the probability of occurrence of at least one spill in the 1000 to 10,000 gallon range over an operating period of one year is 0.9327.

Spills of this magnitude are a result of both small rate spills coupled with a long expected spill time and large rate spills coupled with a relatively short expected spill time.

We can also observe from Table 4-2 that a decrease in the operating period requirement results in a significant decrease in the probability of occurrence of the spill categories.

Figure 4-1 has been constructed to show the combined result of spill producing events and their associated expected spill times. The result of a delay in accomplishing a manual shutdown is shown by the manual shutdown delay branches in the fault tree. For examples, the small rate spill events that contribute to a spill volume of 1000 to 10,000 gallons can tolerate a time to complete shutdown of up to 370 minutes before the higest rate event in this group, i.e., 1/2 inch diameter hose leak, will produce a spill that exceeds 10,000 gallons. As a further illustration, the high spill rate event, one single hose failure or two hose

TABLE 4-2

PROBABILITY OF OCCURRENCE OF SPILL CATEGORIES

Figure 4-1

Spill Volume (gal)	Operating Period 1 year	6 months	3 months
$< 10^2$			
$10^2 - 10^3$	.5041	.2958	.1608
$10^3 - 10^4$	.9327	.7414	.5244
$10^4 - 10^5$	.1615	.0859	.0428
$> 10^5$	.0023	.0012	.0006

Figure 4-2

Spill Volume (gal)	Operating Period 1 year	6 months	3 months
$< 10^2$	.8853	.6714	.4290
$10^2 - 10^3$	.5668	.3462	.1920
$10^3 - 10^4$	.3235	.1789	.0935
$10^4 - 10^5$	.0110	.0364	.0179
$> 10^5$	.0009	.0005	.0002

Figure 4-3

Spill Volume (gal)	Operating Period 1 year	6 months	3 months
$< 10^2$	.8979	.6809	.4340
$10^2 - 10^3$	.5693	.3448	.1900
$10^3 - 10^4$	.3872	.2519	.1776
$10^4 - 10^5$	.0005	.0002	.0001

TABLE 4-2 (Continued)

Figure 4-4

Spill Volume (gal)	Operating Period 1 year	6 months	3 months
$< 10^2$	.7544	.5195	.3100
$10^2 - 10^3$	.3525	.2103	.1098
$10^3 - 10^4$	.1072	.0098	.0050
$10^4 - 10^5$	~0	~0	~0
$> 10^5$	~0	~0	~0

Figure 4-5

Spill Volume (gal)	Operating Period 1 year	6 months	3 months
$< 10^2$	.7941	.5469	.3200
$10^2 - 10^3$	.3435	.1922	.0998
$10^3 - 10^4$	.0007	.0004	.0002
$10^4 - 10^5$	~0	~0	~0

Figure 4-6

Spill Volume (gal)	Operating Period 1 year	6 months	3 months
$< 10^2$	.5041	.2958	.1608
$10^2 - 10^3$	.4155	.2962	.1800
$10^3 - 10^4$	.5932	.4143	.2517
$10^4 - 10^5$	.0793	.0419	.0206
$> 10^5$	.0034	.0017	.0008

TABLE 4-2 (Continued)

Figure 4-7

Spill Volume (gal)	Operating Period 1 year	 6 months	 3 months
$< 10^2$	.8284	.5880	.3600
$10^2 - 10^3$	.8177	.6224	.3510
$10^3 - 10^4$	.3780	.2471	.1753
$10^4 - 10^5$	.0039	.0017	.0009

Figure 4-8

Spill Volume (gal)	Operating Period 1 year	 6 months	 3 months
$< 10^2$	.6111	.3778	.212
$10^2 - 10^3$	.2922	.1621	.1077
$10^3 - 10^4$	.0558	.0293	.0139
$10^4 - 10^5$	.0834	.0428	.0216
$> 10^5$	.0012	.0006	.0003

Figure 4-9

Spill Volume (gal)	Operating Period 1 year	 6 months	 3 months
$< 10^2$	.6197	.3831	.2150
$10^2 - 10^3$	.2901	.1599	.0820
$10^3 - 10^4$	.1429	.0689	.0356
$10^4 - 10^5$	.0007	.0004	.0003

failures, produce spills in the 1000 to 10,000 gallon range when combined with their expected shutdown time of four (4) minutes. If the shutdown is delayed for a time of between ten (10) and fifty (50) minutes, then these events will produce spills in the 10^4 to 10^5 gallon range.

Since the probability of a complete failure of the manual shutdown system is relatively low, see Figure 4-10, all fault trees that describe manual shutdowns have been constructed to show the effect on spill volumes of delays in completing the manual shutdown. Although these delay times may be different for different branches of the fault tree, the probability of these delays has been estimated to be equal to one minus the probability of a successful manual shutdown = (1 - .986) = 0.014.

In order to illustrate the relationship of events on the fault trees, we will discuss in detail the information that is contained in Figure 4-1.

The first spill category that is ordinarily considered is spill volumes of 100 gallons or less. This spill category is not shown in this fault tree because the combination of the long detection time with the spill rate produced by a 1/8-inch diameter hose leak produces a spill volume that exceeds 100 gallons. This event produces a spill of approximately 240 gallons when combined with a normal manual shutdown and a total spill time of up to 500 minutes can be tolerated before producing a spill that exceeds 1000 gallons.

The 1000 to 10,000 gallon spill category for this case is produced by the spill events 1 inch x 1/16-inch weld leak, 1 inch by 1/16-inch gasket failure, small valve packing leak, and a 1/2-inch diameter hose leak combined with a manual shutdown that could take up to 370 minutes. This spill category will also result from spills that are produced by a major gasket failure, a major valve packing leak, or a 8-inch by 1/16-inch weld leak as long as the manual shutdown time does not exceed 154 minutes. Additionally, the large spill rate events, single hose failure, single pipe failure, both hoses fail or both pipes fail when combined with a normal manual shutdown also produce spills in the 1000 - 10,000 gallon category. These same events will produce spills in the 10,000 - 100,000 gallon range if the manual shutdown is delayed for more than ten (10) minutes.

Finally, the events total gasket failure, single hose or transfer pipe fails with three cargo pumps supplying flow, or both hoses or transfer pipes fail with one pump supplying flow for one tranfer line and three pumps supplying flow for

the other line, produce spills in the 10,000 - 100,000 gallon category when combined with a normal manual shutdown. Again, the shutdown delays shown on the fault tree, i.e., a delay time of greater than 385 minutes for the total gasket failure event or greater than 33 minutes for the other events result in spills greater than 100,000 gallons.

Because of the impact of spill detection time on spill volumes for the small leak rate events, we decided to modify the assumed operations by adding a roving deck watch.

The assignment for this watch is to patrol the main deck from the after superstructure to the bow for the purpose of looking for leaks in the fuel transfer system. The estimated time for a circuit of this area is fifteen (15) minutes with 2/3 of this time spent in the vicinity of the transfer piping and 1/3 of this time spent near the bow including an observation of the SPM. Assuming that a leak will be detected within one (1) minute if it occurs when the watch is in the general area but will require eight (8) minutes to detect if it occurs when the watch is not in the area of the leak leads to an expected leak detection time for small rate spills of about 3.5 minutes. Combining this with an additional minute of communication time and three (3) minutes of shutdown time, yields a total expected spill time of 7.5 minutes for small rate spills. Since large rate spills are still likely to be detected by the pump room watch, their expected spill time remains four (4) minutes.

These spill times are combined as before with the spill rates to produce the spill volumes shown on the fault tree in Figure 4-2. Examination of these results shows that the reduction in expected spill detection time that is made possible by the roving deck watch results in an order of magnitude reduction in the spill volumes that result from small rate spills. In fact, three of the spill producing events that previously produced spill volumes in the 1000 - 10,000 gallon range now produce spills of less than 100 gallons if a normal manual shutdown is conducted. Table 4-2 shows the impact of the roving deck watch on spill probabilities. As can be seen in the table, the probability of small volume spills increase due to the increased number of spill events which now produce spills of small volume.

Since small leak rate events are the type that are most likely to produce a fuel spill and since the addition of a roving deck watch produces a reduction in the resulting spill size, the use of a roving deck watch appears to be justified. Therefore, further discussion of deck fuel spill situations will be under the assumption that a roving deck watch as

previously described will be used to assist with spill detection.

As a further aid to reducing the size of potential spill volumes, a remotely actuated emergency shutdown system (ESD) is considered in addition to the present manual spill isolation system. This system will respond to a pull box actuated signal to stop cargo transfer pumps and close power operated valves to reduce the leak isolation time. In this case, shutdown time is reduced by two (2) to two and one-half (2 1/2) minutes. This gives a total expected spill time of 5.5 minutes for small rate spills and 1.5 minutes for large rate spills. This yields the spill volumes shown on the fault tree in Figure 4-3.

Examination of Figures 4-1, 4-2, and 4-3 and the information contained in Table 4-2 shows that the addition of an ESD system significantly reduces the chances of the larger spill categories.

Additionally, for the offloading condition, an analysis is performed for the condition where a spill is detected and an emergency shutdown is actuated but fails to operate. Potential failure modes for the ESD system are illustrated by the fault tree in Figure 4-11. We assume that when the ESD is actuated, an audible ESD alarm is sounded. Thus personnel on watch should be aware that the ESD system has been actuated and prepared to detect ESD failures and carry out a successful manual shutdown. The expected spill times for this scenario are 8.5 minutes for the small rate spills and 4.5 minutes for the large rate spills. The resulting spill volumes are also shown in Figure 4-3.

The effect of the addition of a ESD system is to significantly reduce the probability of having spills of 10,000 gallons are greater. While the events that produce spills of this magnitude have a low probability of occurrence, the potential hazards from large spills are so great that the potential benefits of having an ESD system seem to be sufficient to justify the system.

When offloading is in progress, spills that occur in the pump room will most likely be detected by the pump room watch. This results in an expected spill time of 3.5 minutes for the manual shutdown case for all spills. If an emergency shutdown system is added, the total expected spill time is reduced to 1.5 minutes. If the ESD is actuated and fails to operate and is followed by a successful manual shutdown, the expected total spill time is 4.5 minutes. The resulting

spill volumes for these two scenarios are shown on the fault trees in Figures 4-4 and 4-5, respectively.

It is important to note that in the case of transfer pipe failures in the pump room that produce large rate spills, i.e., 1000-3000 gpm, the concept of a normal manual shutdown is probably not valid. In fact, failures of this type are likely to require the pump room personnel on watch to rapidly evacuate the pump room without attempting to isolate the spill. However, failures of this type have a low probability of occurrence.(26)

When an ESD system is installed, these large rate spills are much more likely to be controlled by action of ship's personnel. The ESD can be actuated by the pump room watch as he evacuates the space or can be actuated from other locations.

The Single Point Moor (SPM) is not manned and is located approximately 200 feet from the bow of the storage tanker. Spills produced by failure of SPM components are most likely to be detected by personnel on watch on the storage tanker. Reliability of this visual detection is questionable especially with small rate spills or under conditions of reduced visibility. If the SPM spills are detected by the roving deck watch at the earliest opportunity after the spill occurs, then the expected time to detect a small rate spill is 8 1/3 minutes. This leads to an expected total spill time of 12 1/3 minutes for the small rate spills. Large rate spills will still probably be detected by the pump room watch on the storage tanker and thus, have an expected total spill time of 4 minutes.

Before proceeding with the discussion, we should note that the detection of SPM related spills is a difficult process. During nighttime hours or other periods of restricted visibility, visual detection of SPM spills by the roving deck watch on the storage tanker will be almost impossible. It is extremely important that this watch be instructed to check the surface of the water near the tanker for visual indication of fuel on the surface of the water. Also, since the storage tanker will most likely be on the downwind side of SPM, it is possible that the deck watch may detect a SPM spill by smelling vapors from the fuel.

As before, the addition of an ESD system reduces the expected spill time to 10 minutes for small rate spills and 1.5 minutes for large rate spills. Also, if ESD is initiated and fails to operate, a successful manual shutdown is conducted. This condition results in total expected spill time

of 13 minutes and 4 1/2 minutes for small rate and large rate spills, respectively. The resulting spill volumes for SPM spills are shown on the fault trees in Figures 4-6 and 4-7.

Examination of these fault trees indicates that the addition of an ESD system may eliminate the largest spill volume category, i.e., spills > 10^5 gallons, and significantly decreases the probability of spills that result from large leak rate events.

4.2.2 Loading

The LOADING condition occurs when the storage tanker is receiving fuel from a supply tanker. This can be accomplished in either an astern or along side refueling configuration. With the USNS Taluga or a similar ship as the storage tanker, the along side arrangement will probably be preferred because of the time required to complete the refueling operation in the along side configuration.

In this operational mode, we assume that the supply tanker will have control of the fuel transfer operation. This means that detection of a leak must be communicated to the supply tanker in order to have the fuel transfer pumps securred and the appropriate valves closed. We are assuming a roving deck watch on the storage tanker to assist with leak detection. This results in an expected total spill time of 8 1/3 minutes for small rate spills and 4 minutes for large rate spills. These time estimates are combined with the appropriate spill rates to produce the spill volumes shown on the fault trees in Figure 4-8.

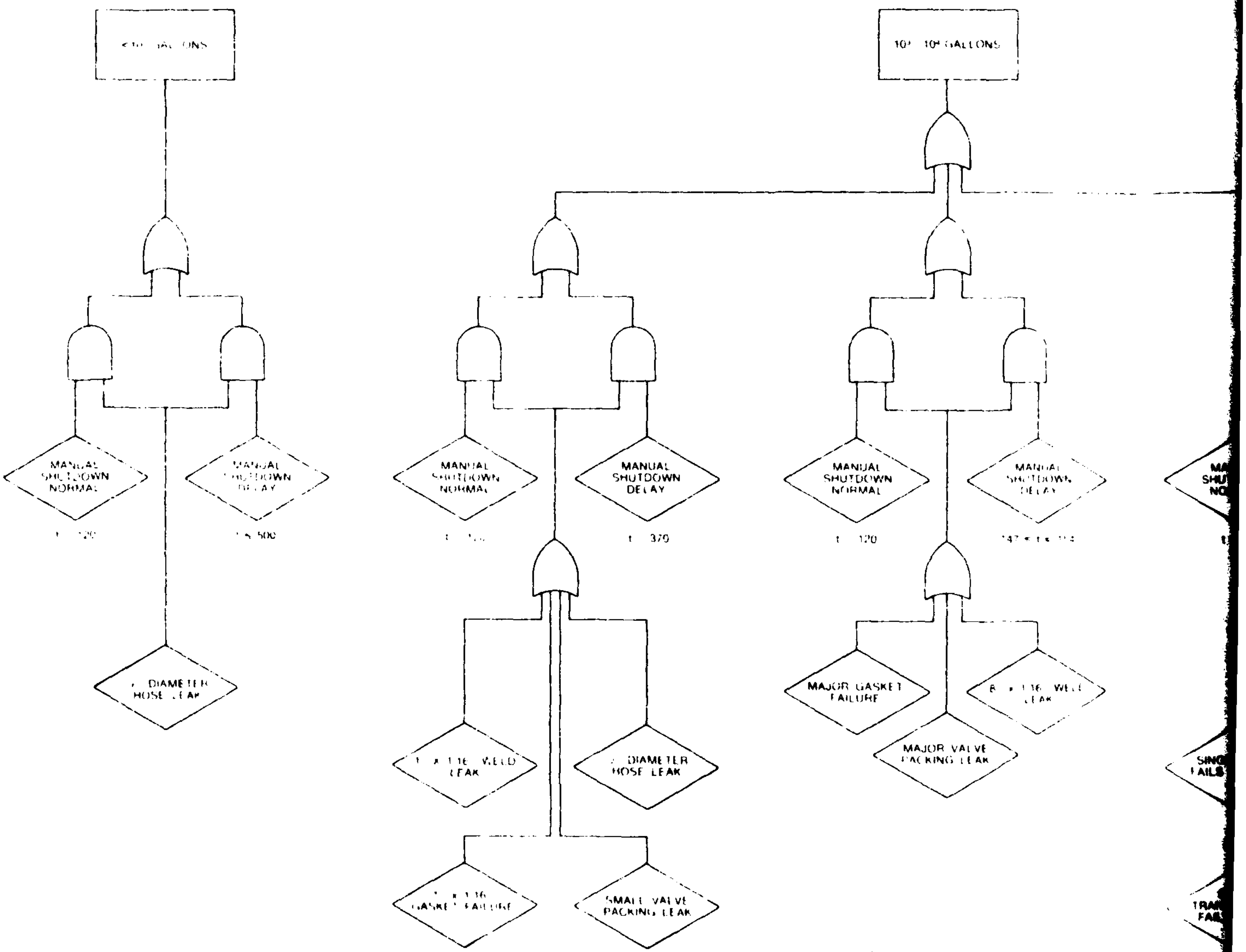
In order for a shutdown scenario that incorporates an ESD to be meaningful for the loading condition, the supply tanker must be equipped with the ESD. Using this assumption, the expected spill times are reduced to 6 1/3 minutes for small rate spills and to 1 1/2 minutes for large rate spills. The resulting spill volumes are shown on the fault tree in Figure 4-9. The most significant result of the addition of the ESD system is that the spill volumes for the large rate spills are reduced by a factor of 3 to 4.

Pump room spills and SPM spills occurring during loading are not significantly different from the offloading condition previously considered. SPM spills are not likely to occur unless offloading is occurring simultaneously with loading. In this event, the SPM spill analysis and the resulting fault tree representations discussed earlier apply.

Spills resulting from operation of the offshore bulk fuel storage system that cause fuel to be spread on the water are SPM spills and tanker deck spills. SPM component failures that are most likely to produce fuel spills are gasket failures, weld leaks, hose leaks, and hose ruptures. Because of the orientation of the tanker and SPM, these spills on water are likely to proceed from the SPM to the vicinity of the tanker. Also, tanker deck spills and/or spills resulting from hose leaks/failures near the tanker are likely to spread over the surface of the water near the tanker. The magnitude of the spills has been described by the previous discussion on deck spills and SPM spills. The hazards associated with these spills are pollution of coastal water and fire danger if the spill is ignited.

Large leak rate spills that cause fuel to be spilled upon the water should be detected by the pump room watch in a relatively short period of time. Small rate spills can go undetected for time periods that result in a significant volume of fuel spilled. Because the events that produce these small rate spills are the most likely of the spill producing events, the use of a system to automatically detect spills on the surface of the water near the SPM and the tanker is probably desirable. Detection systems to perform this function will be discussed in a later section of this report.

A final spill category to consider is those spills that can result from non-normal operation of the fuel storage system. Events such as grounding, collision, and hostile action have the potential for producing spills that are greater than 100,000 gallons. The probability of occurrence of events of this type is quite small. The fault tree for this situation is shown in Figure 4-12.



MANUAL SHUTDOWN NORMAL
MANUAL SHUTDOWN DELAY
DIAMETER HOSE LEAK
MANUAL SHUTDOWN NORMAL
MANUAL SHUTDOWN DELAY
t 370
DIAMETER HOSE LEAK
SMALL VALVE PACKING LEAK
MANUAL SHUTDOWN NORMAL
MANUAL SHUTDOWN DELAY
t 120
MAJOR GASKET FAILURE
MAJOR VALVE PACKING LEAK

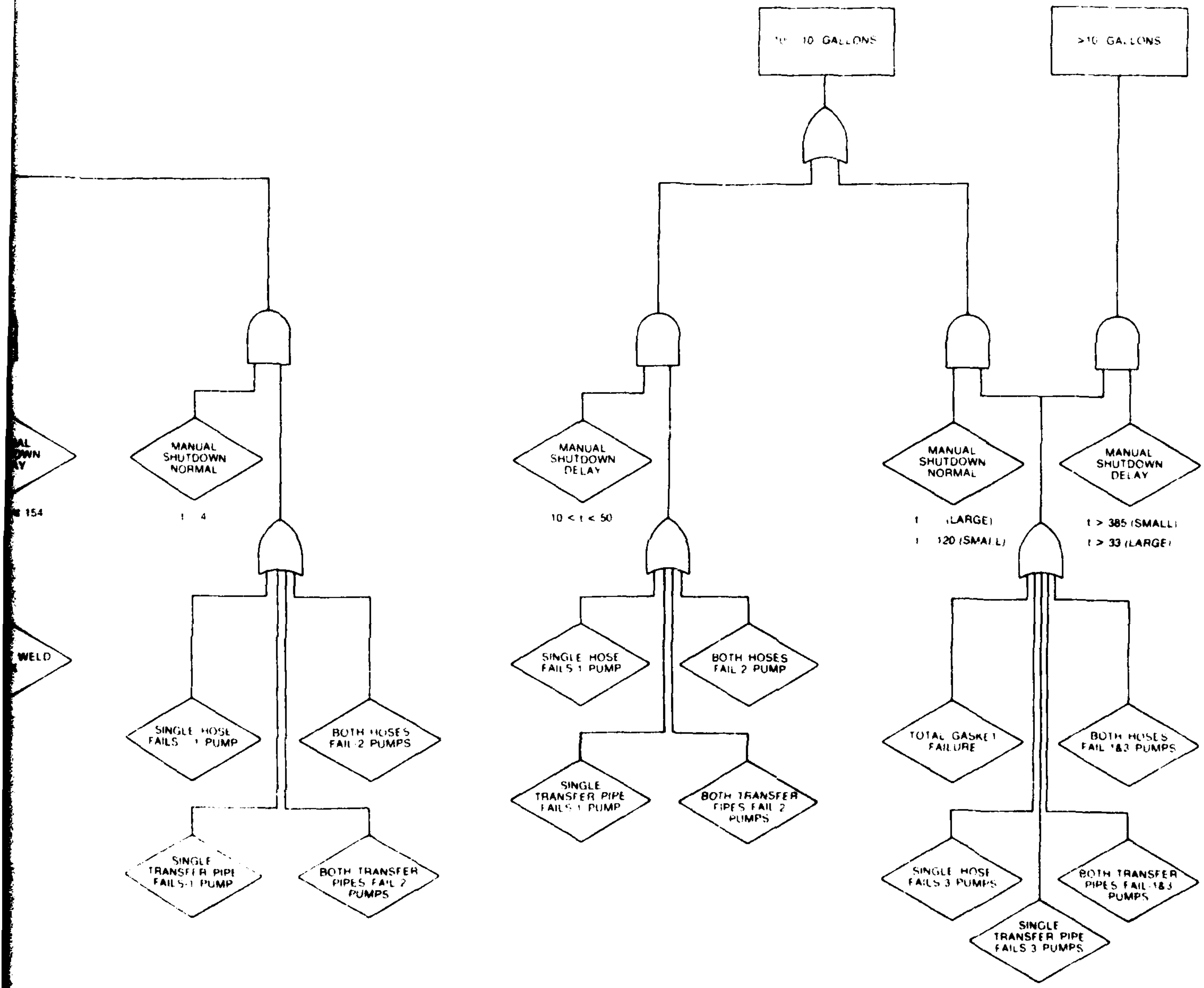
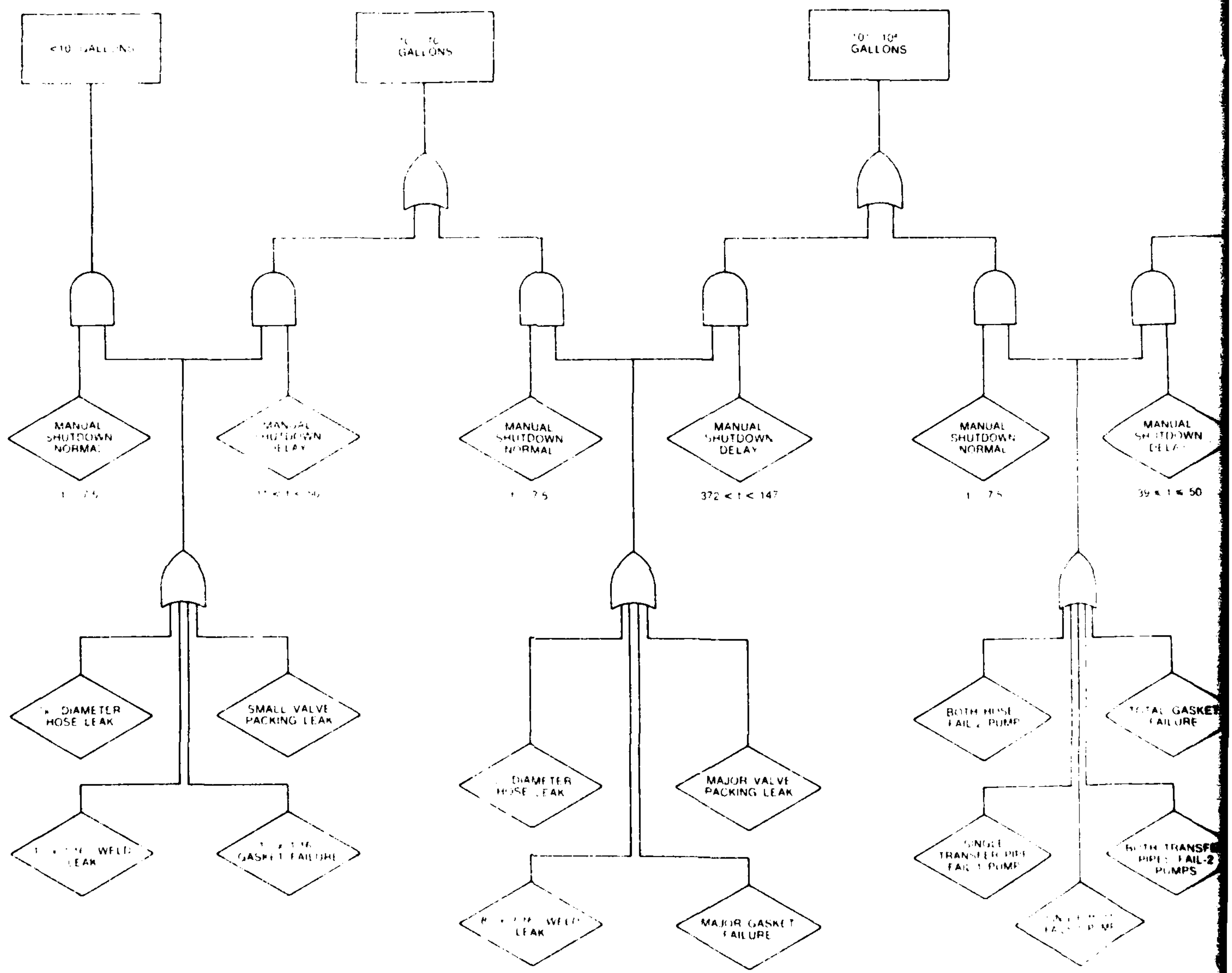


FIGURE 4-1

OFFLOADING DECK SPILLS: MANUAL DETECTION WITHOUT PATROL AND MANUAL SHUTDOWN

2


GALLONS
GALLONS
MANUAL
SHUTDOWN
NORMAL
MANUAL
SHUTDOWN
DELAY
372 < t < 147
39 ≤ t ≤ 50
DIAMETER
HOSE LEAK
SMALL VALVE
PACKING LEAK
GASKET FAILURE
MAJOR VALVE
PACKING LEAK
MAJOR GASKET
FAILURE
BOTH HOSE
SINGLE
TRANSFER PIPE
BOTH TRANSFER
PIPES FAIL-2
PUMPS

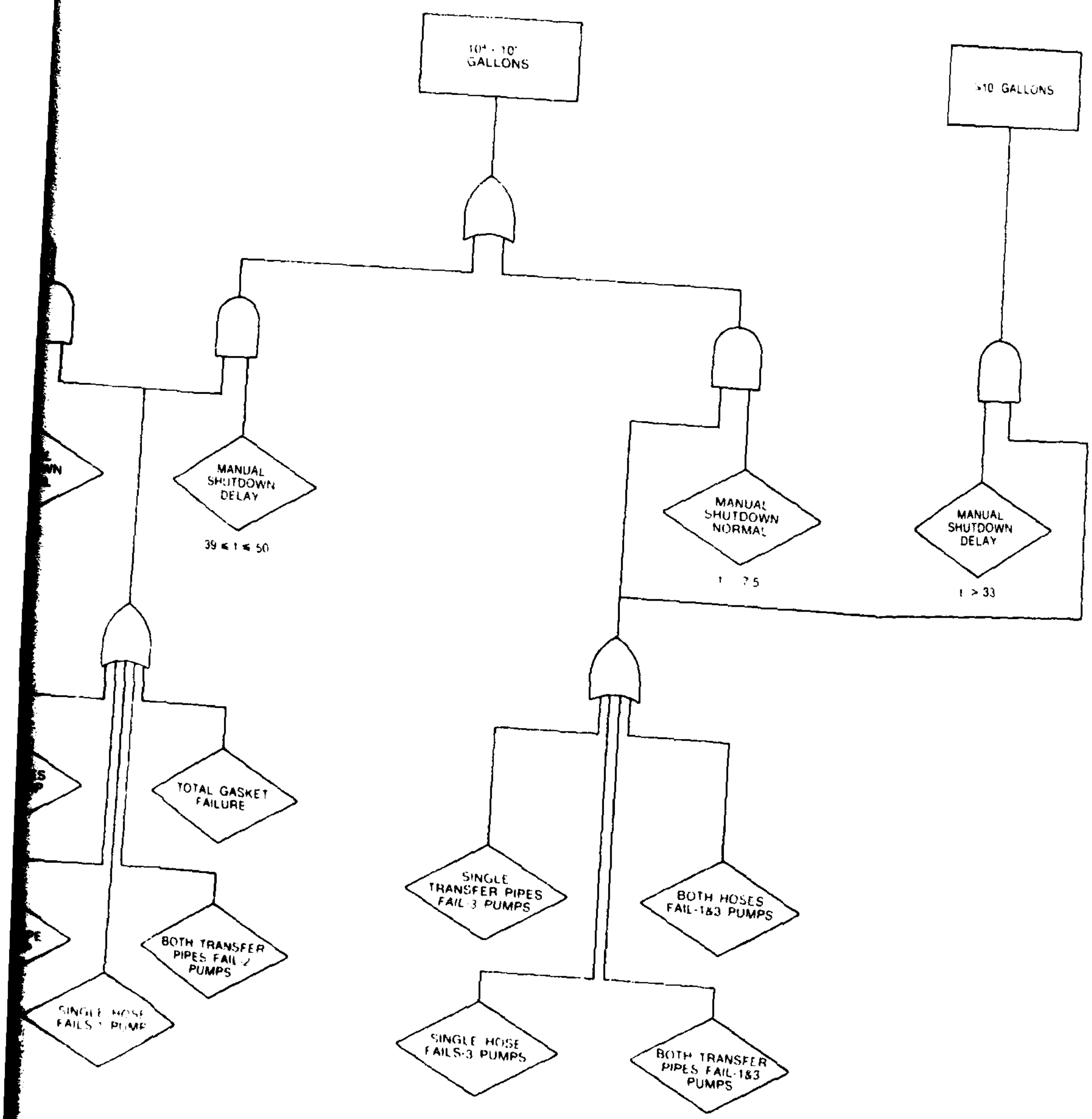
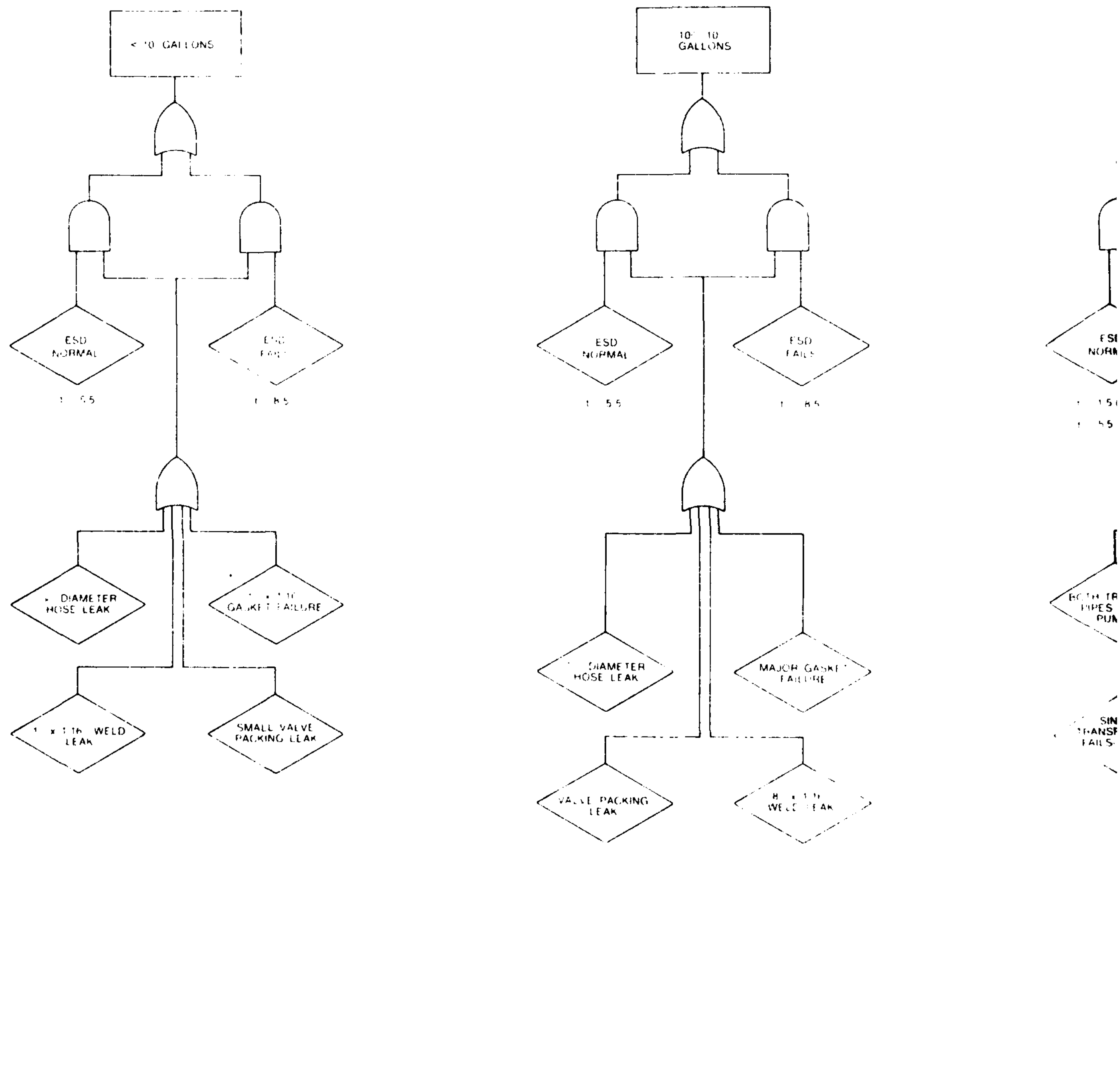


FIGURE 4-2

OFFLOADING DECK SPILLS: MANUAL DETECTION WITH PATROL AND MANUAL SHUTDOWN



< 10 GALLONS
ESD NORMAL
ESD FAILS
DIAMETER HOSE LEAK
GASKET FAILURE
WELD LEAK
SMALL VALVE PACKING LEAK
GALLONS
ESD NORMAL
ESD FAILS
DIAMETER HOSE LEAK
MAJOR GASKET FAILURE
VALVE PACKING LEAK
WELD LEAK

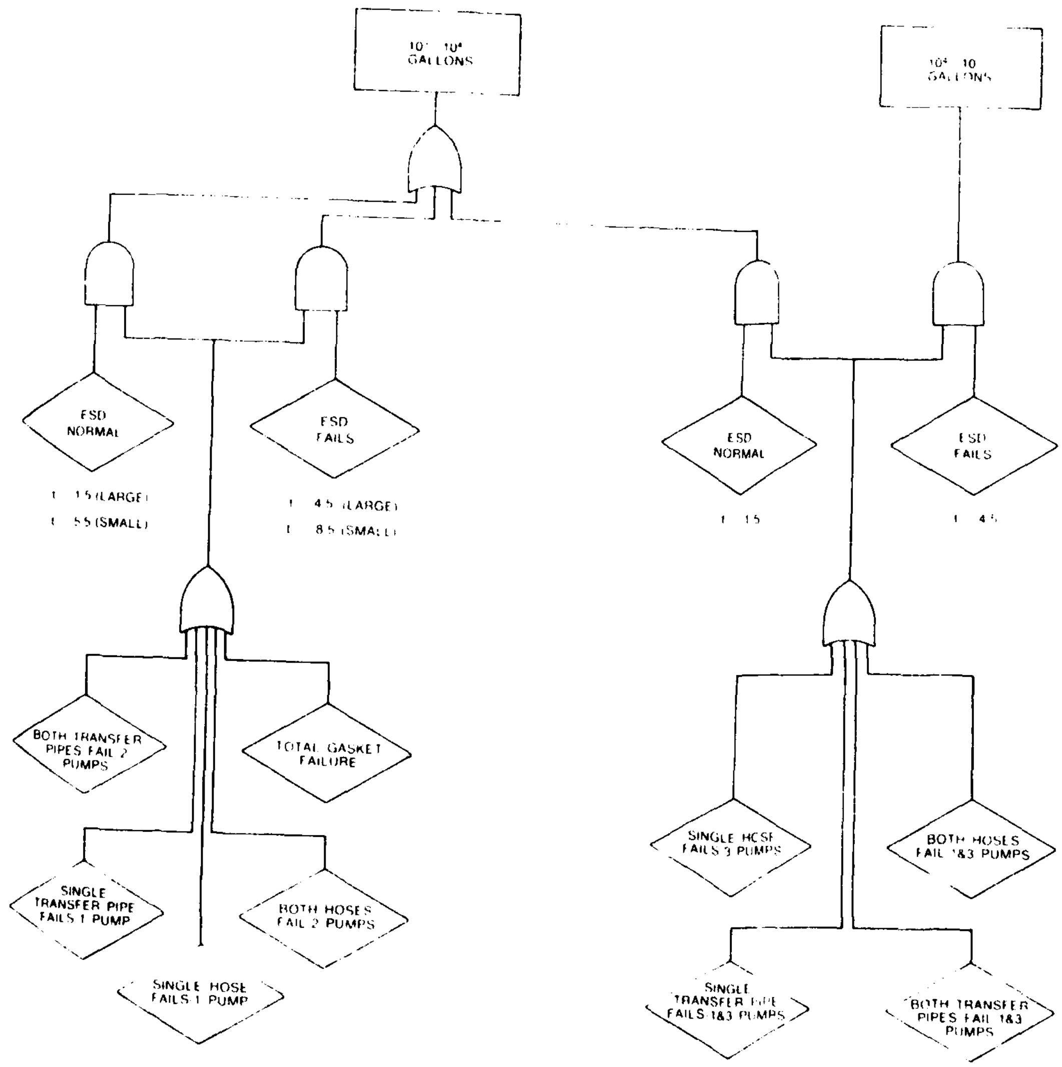
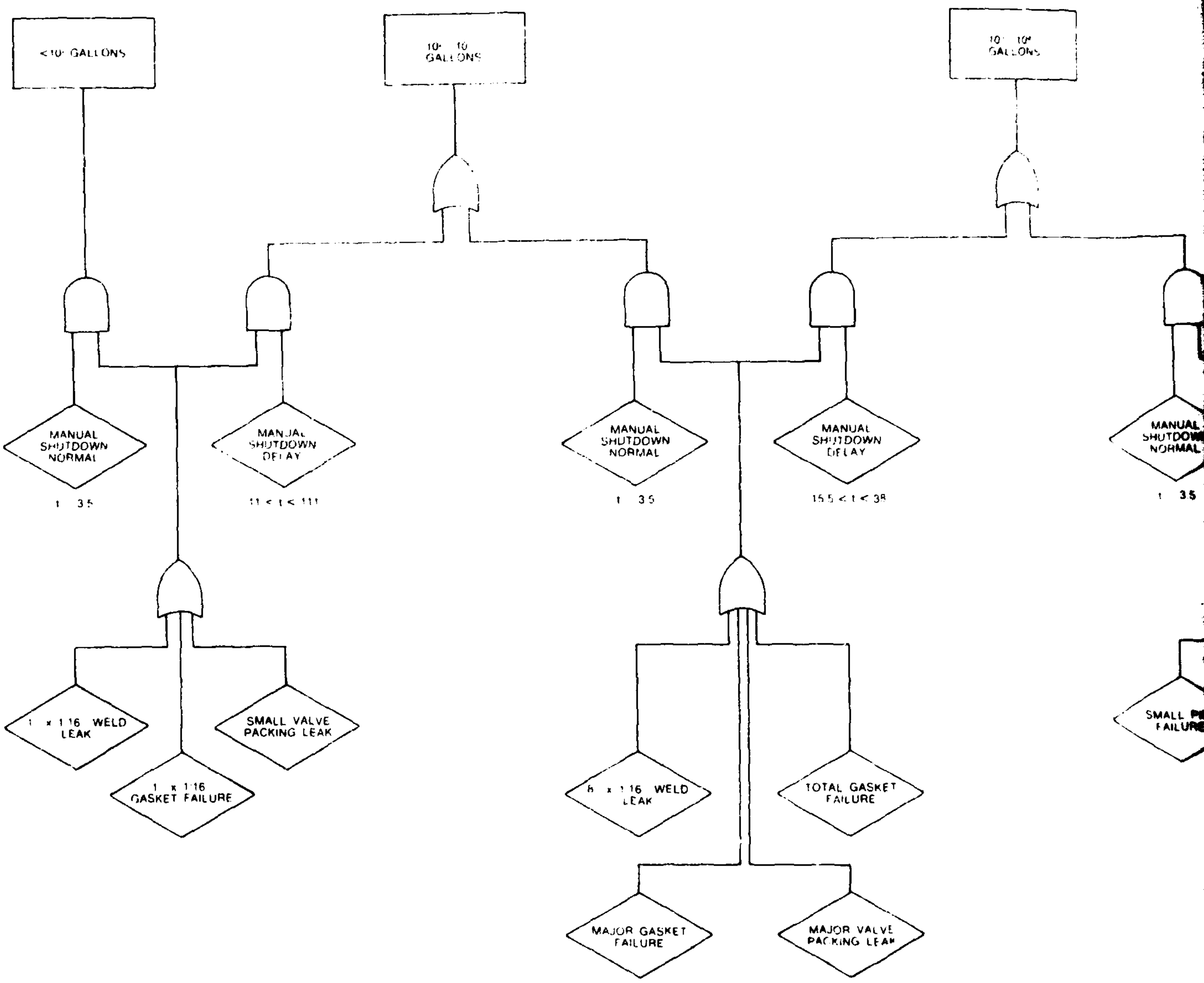


FIGURE 4-3

OFFLOADING DECK SPILLS: MANUAL DETECTION WITH PATROL AND ESD



<10 GALLONS
10 10 GALLONS
10 10 GALLONS
MANUAL SHUTDOWN NORMAL
t 3.5
MANUAL SHUTDOWN DELAY
11 < t < 111
MANUAL SHUTDOWN NORMAL
t 3.5
MANUAL SHUTDOWN DELAY
15.5 < t < 38
MANUAL SHUTDOWN NORMAL
t 3.5
1 x 1/16 WELD LEAK
1 x 1/16 GASKET FAILURE
SMALL VALVE PACKING LEAK
6 x 1/16 WELD LEAK
TOTAL GASKET FAILURE
MAJOR GASKET FAILURE
MAJOR VALVE PACKING LEAK
SMALL
FAILURE

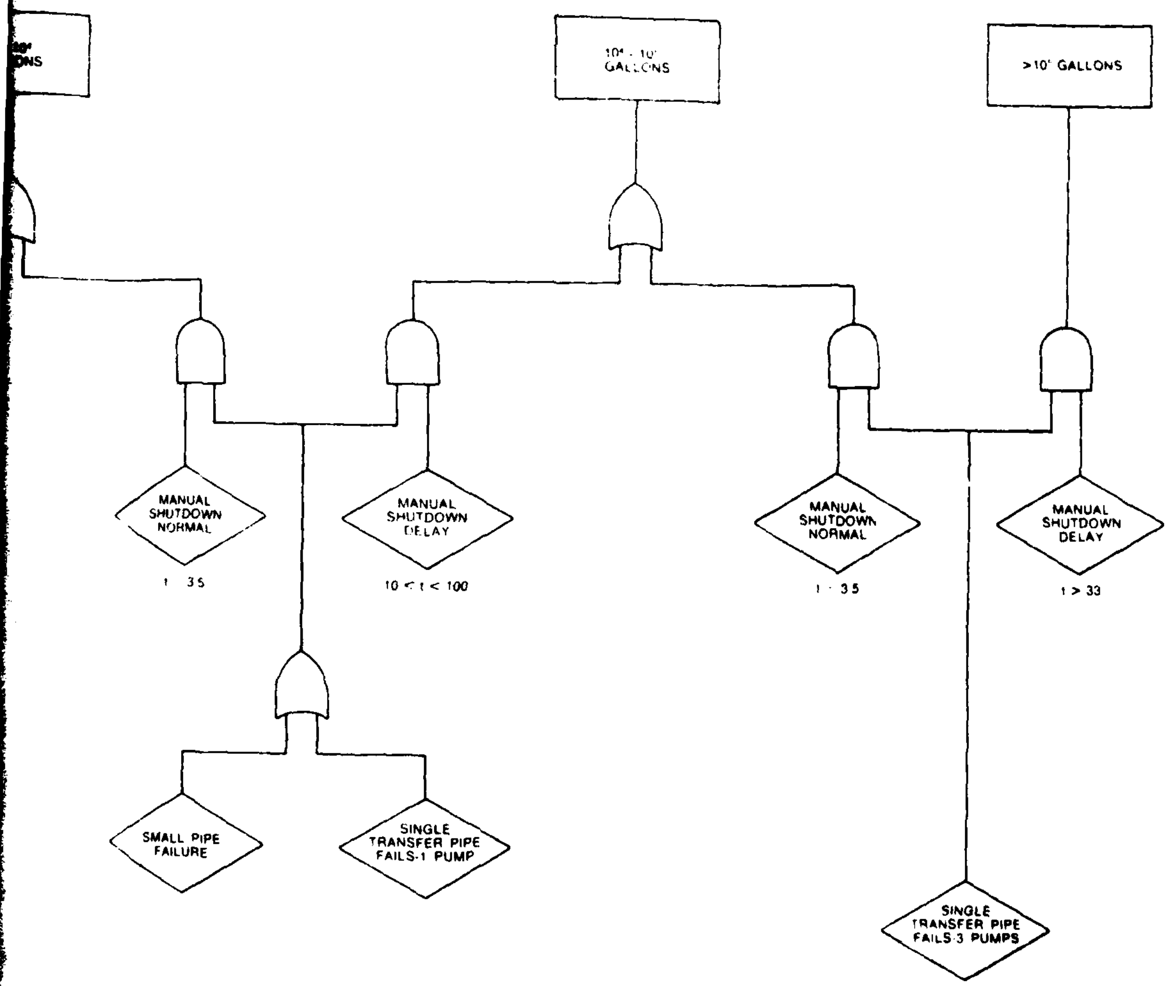
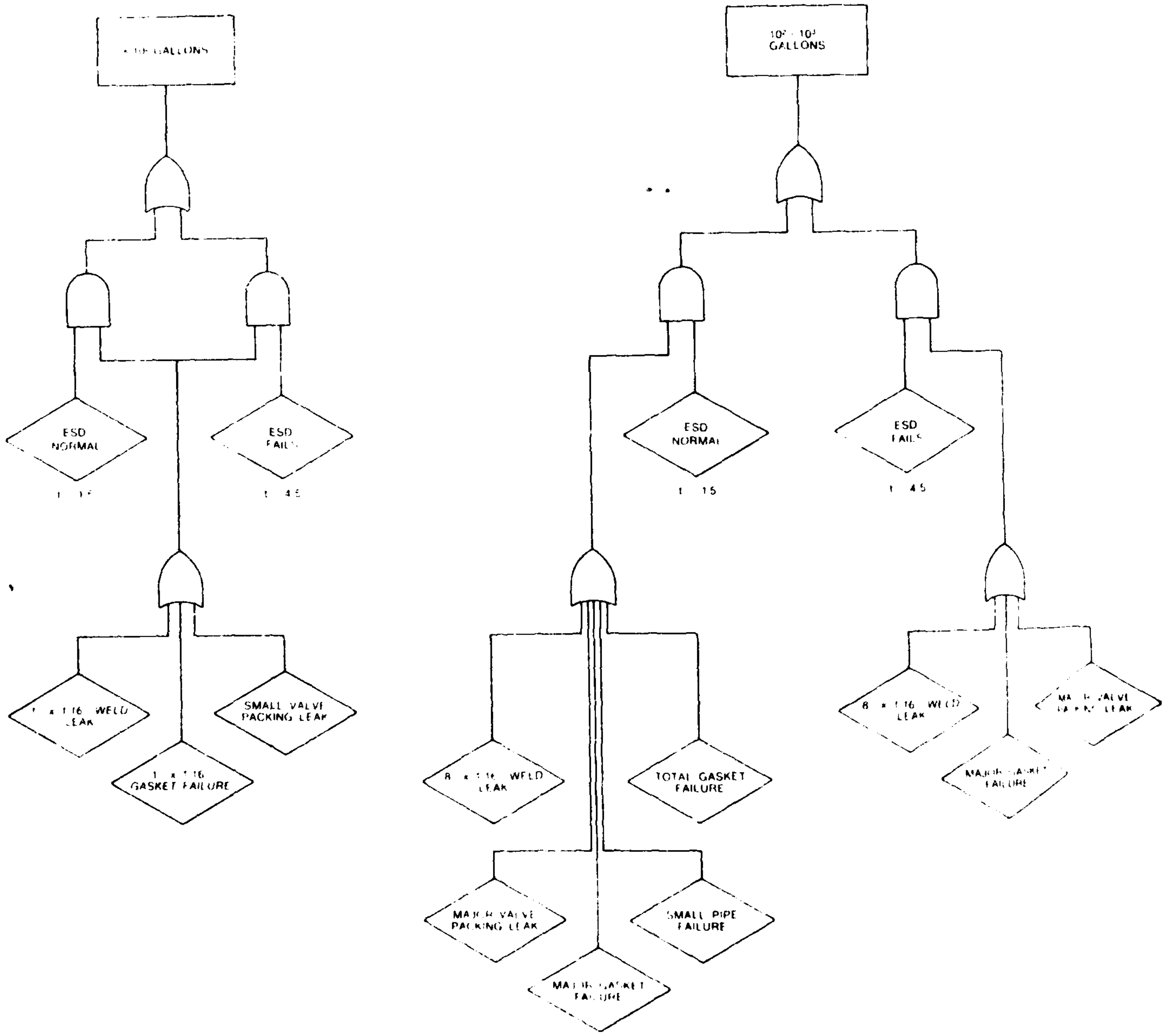


FIGURE 4-4

OFFLOADING PUMP ROOM SPILLS: MANUAL DETECTION AND MANUAL SHUTDOWN



GALLONS
ESD NORMAL
ESD FAILS
WELD LEAK
SMALL VALVE PACKING LEAK
GASKET FAILURE
GALLONS
ESD NORMAL
ESD FAILS
WELD LEAK
TOTAL GASKET FAILURE
MAJOR VALVE PACKING LEAK
SMALL PIPE FAILURE
MAJOR GASKET FAILURE
WELD LEAK
MAJOR GASKET FAILURE

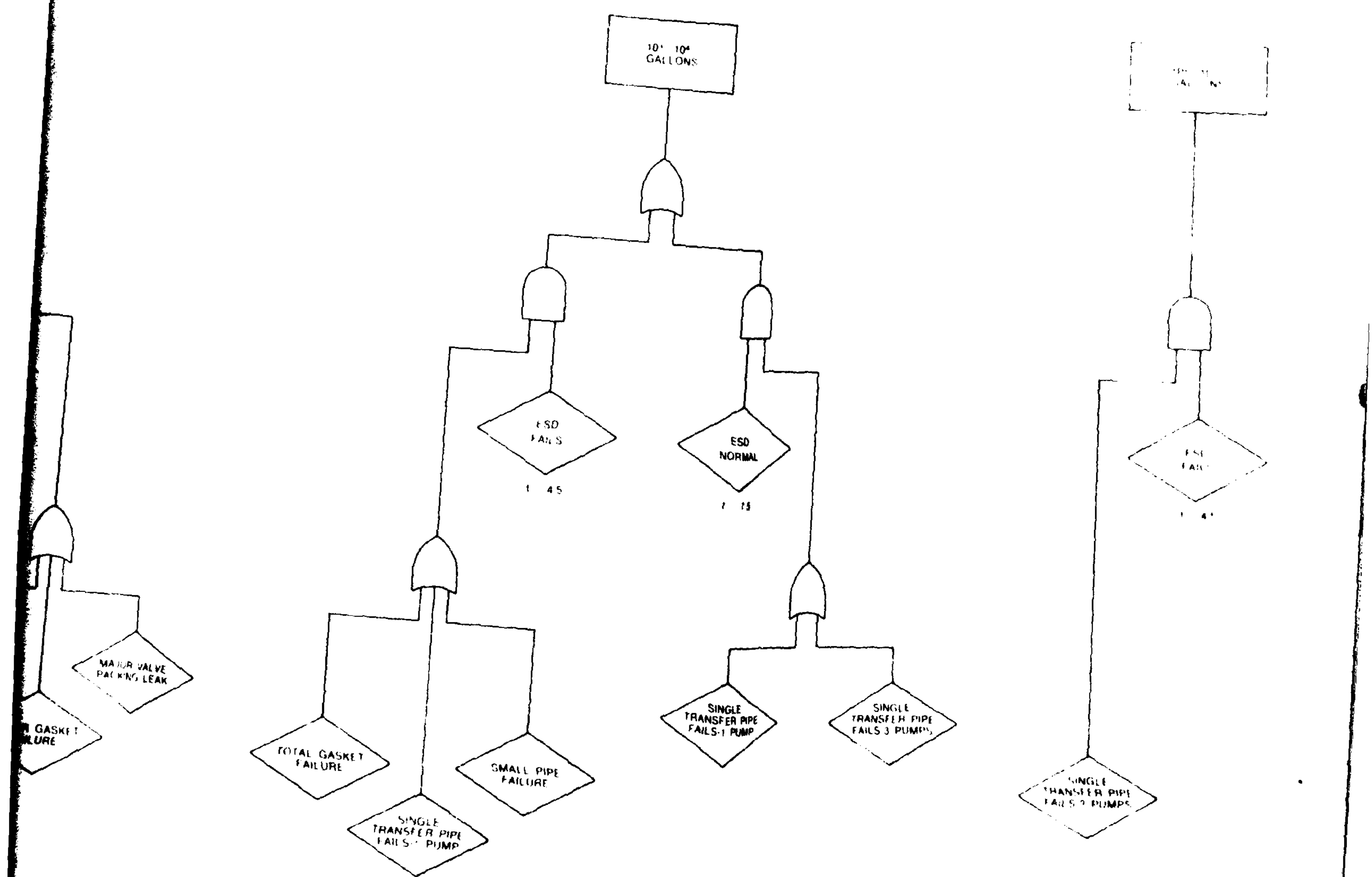
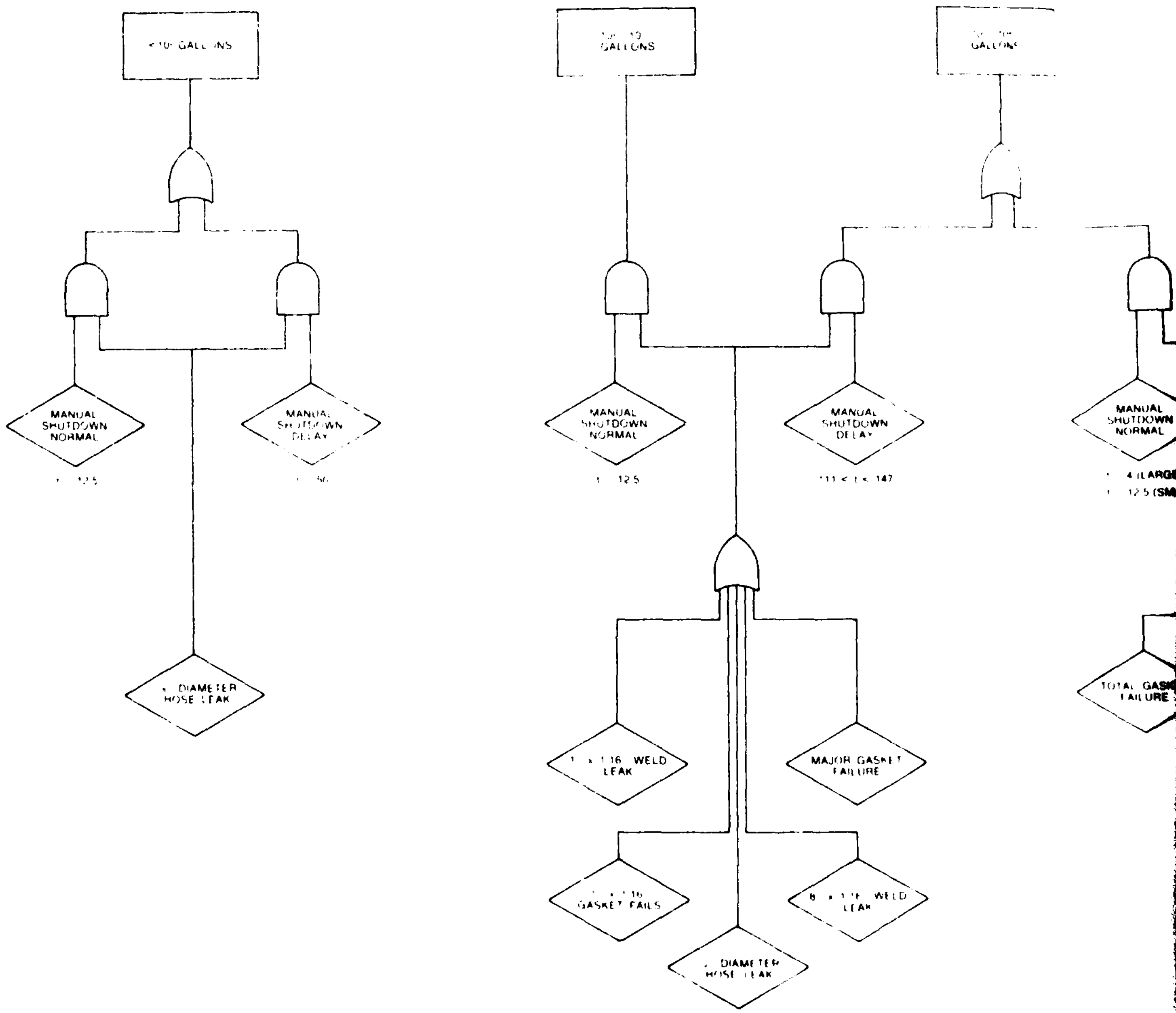


FIGURE 4-5

OFFLOADING PUMP ROOM SPILLS: MANUAL DETECTION AND ESD

2



GALLONS
MANUAL SHUTDOWN NORMAL
MANUAL SHUTDOWN DELAY
DIAMETER HOSE LEAK
MANUAL SHUTDOWN NORMAL
12.5
MANUAL SHUTDOWN DELAY
WELD LEAK
MAJOR GASKET FAILURE
GASKET FAILS
WELD LEAK
DIAMETER HOSE LEAK
MANUAL SHUTDOWN NORMAL

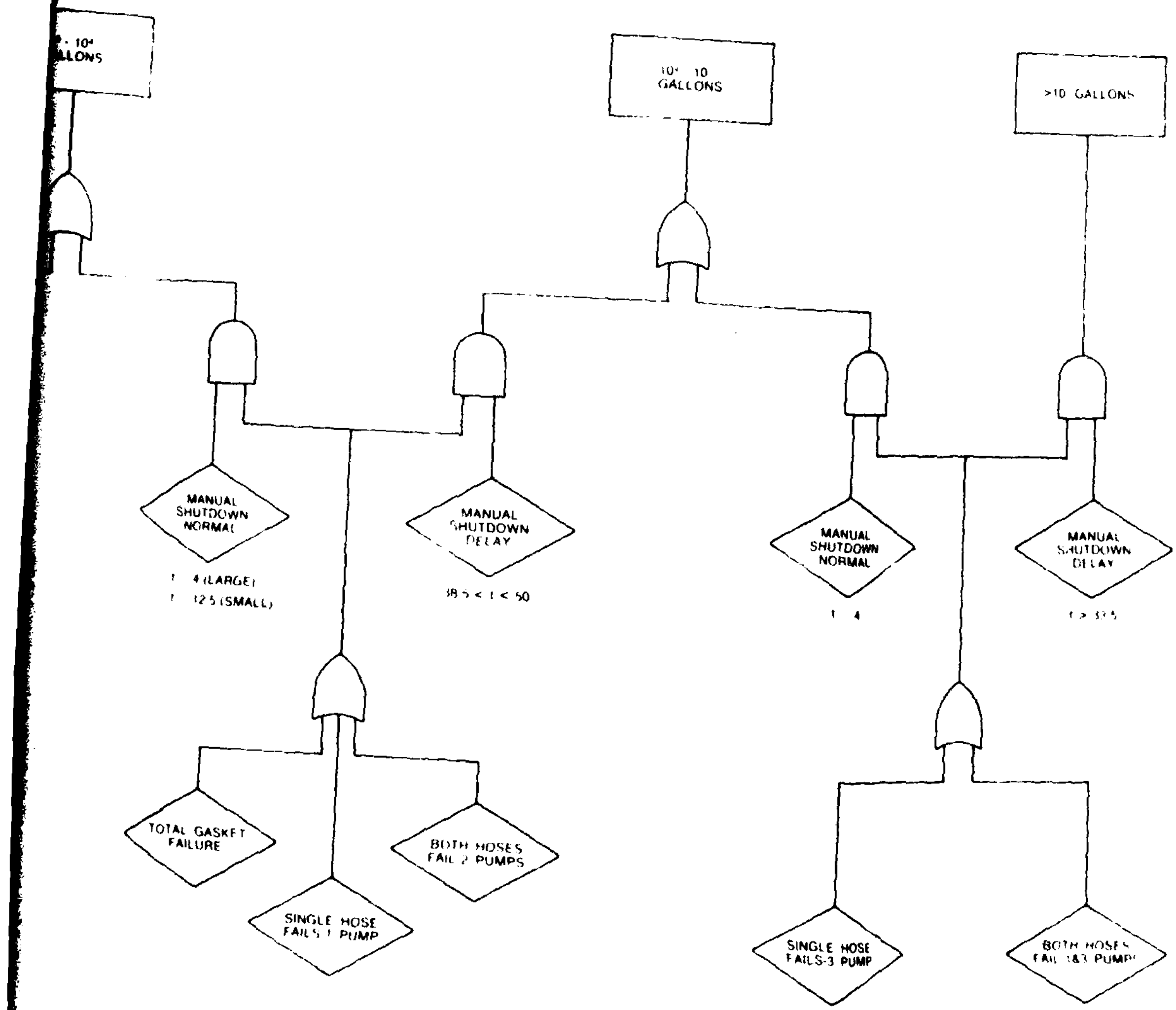
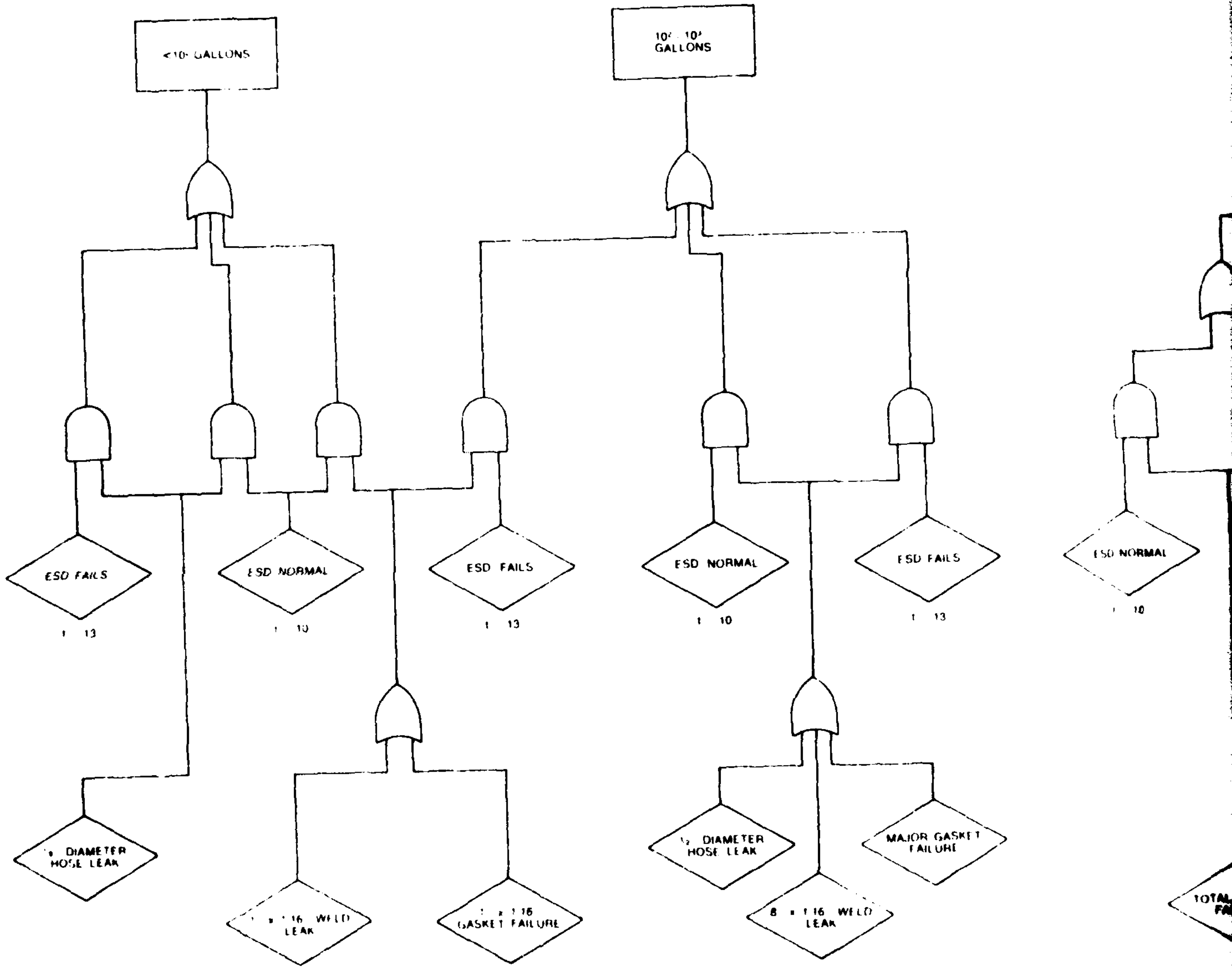


FIGURE 4-6

OFFLOADING SPM SPILLS: MANUAL DETECTION WITH PATROL AND MANUAL SHUTDOWN

2



<10² GALLONS
10² - 10³ GALLONS
ESD FAILS
ESD NORMAL
ESD FAILS
ESD NORMAL
ESD FAILS
ESD NORMAL
½ DIAMETER HOSE LEAK
1/16 WELD LEAK
1/16 GASKET FAILURE
½ DIAMETER HOSE LEAK
8 × 1/16 WELD LEAK
MAJOR GASKET FAILURE

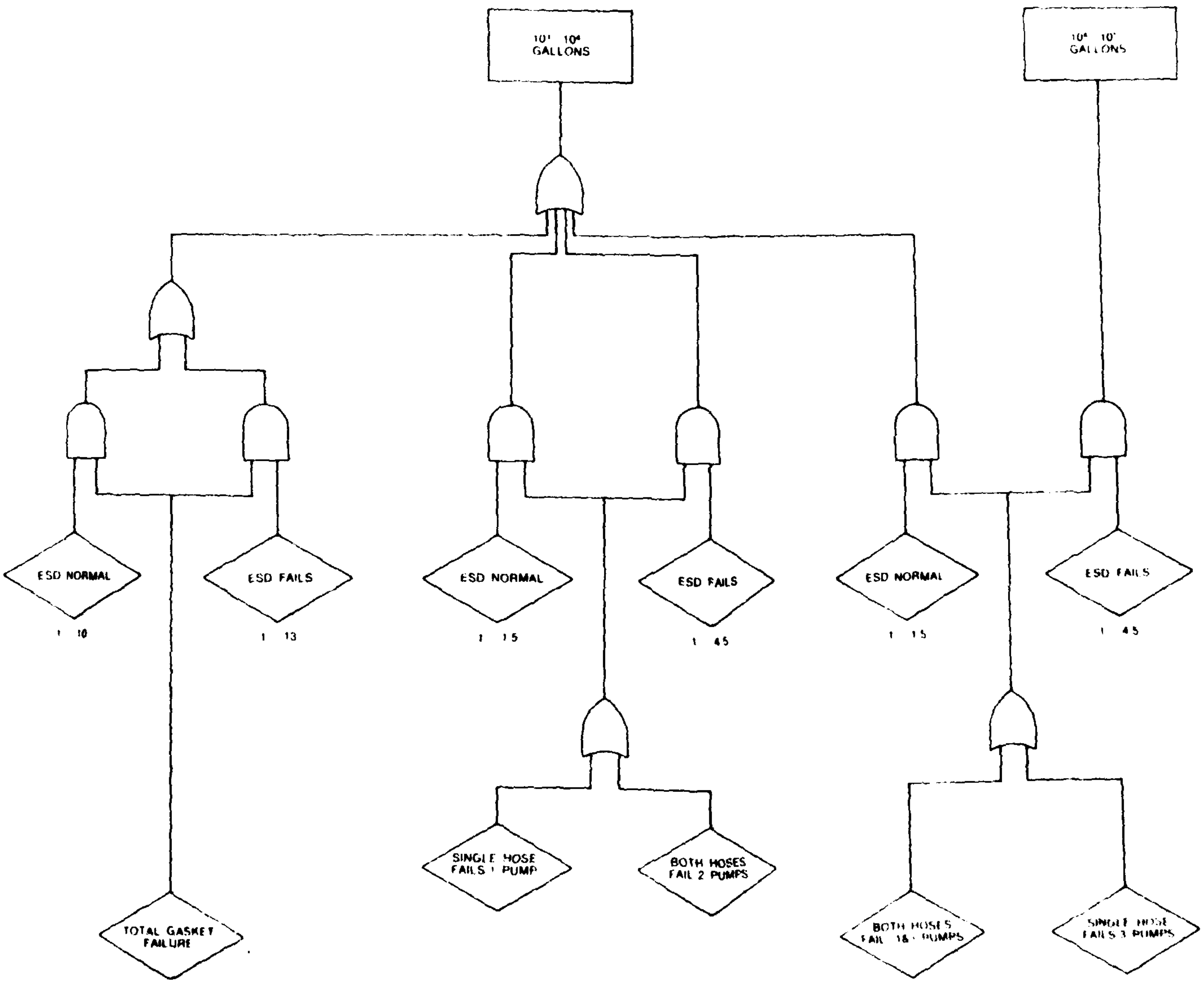
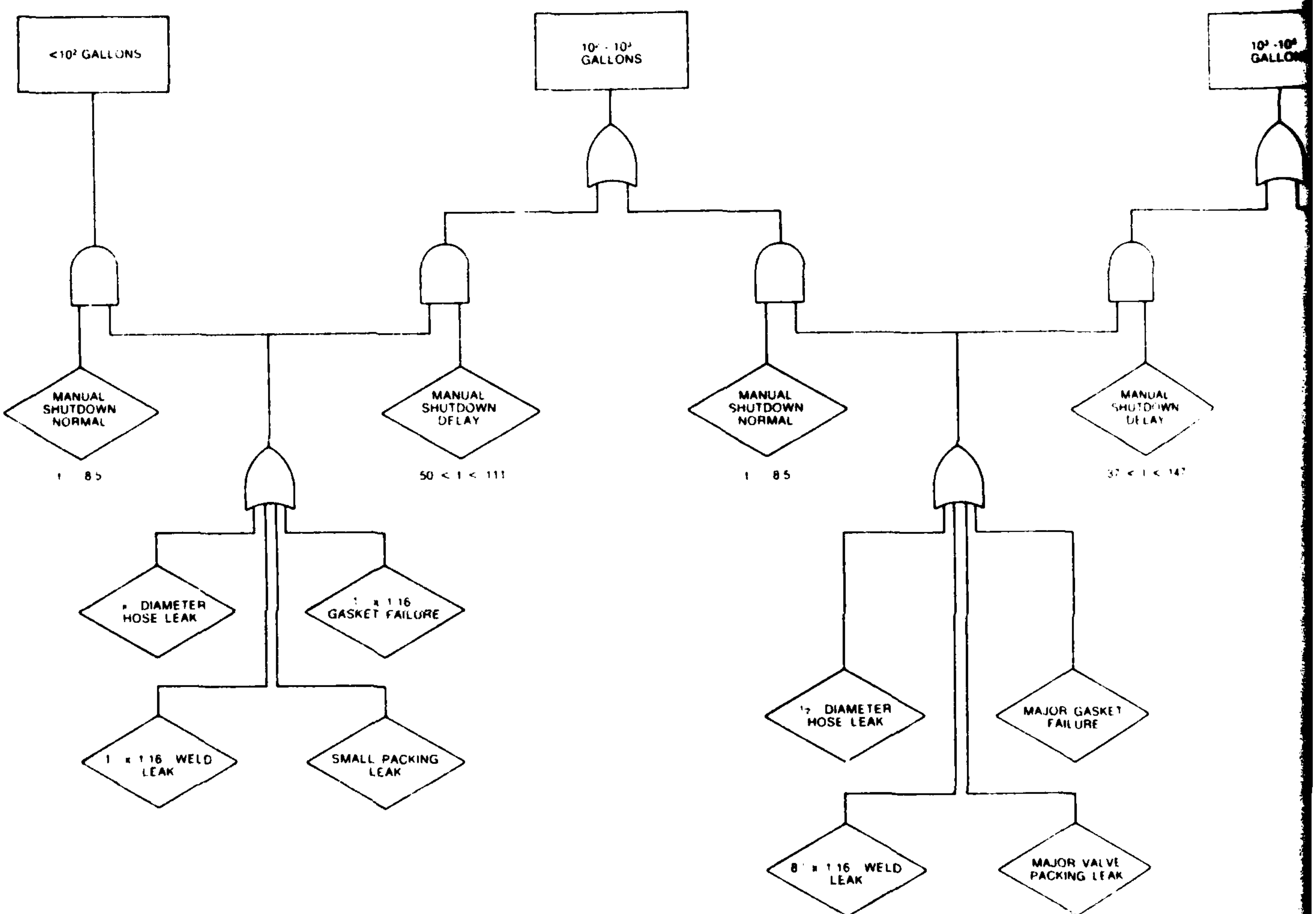


FIGURE 4-7

OFFLOADING SPM SPILLS: MANUAL DETECTION WITH PATROL AND ESD

2



<10² GALLONS
10² - 10³ GALLONS
MANUAL SHUTDOWN NORMAL
MANUAL SHUTDOWN DELAY
50 < t < 111
MANUAL SHUTDOWN NORMAL
MANUAL SHUTDOWN DELAY
DIAMETER HOSE LEAK
GASKET FAILURE
WELD LEAK
SMALL PACKING LEAK
DIAMETER HOSE LEAK
MAJOR GASKET FAILURE
WELD LEAK
MAJOR VALVE PACKING LEAK

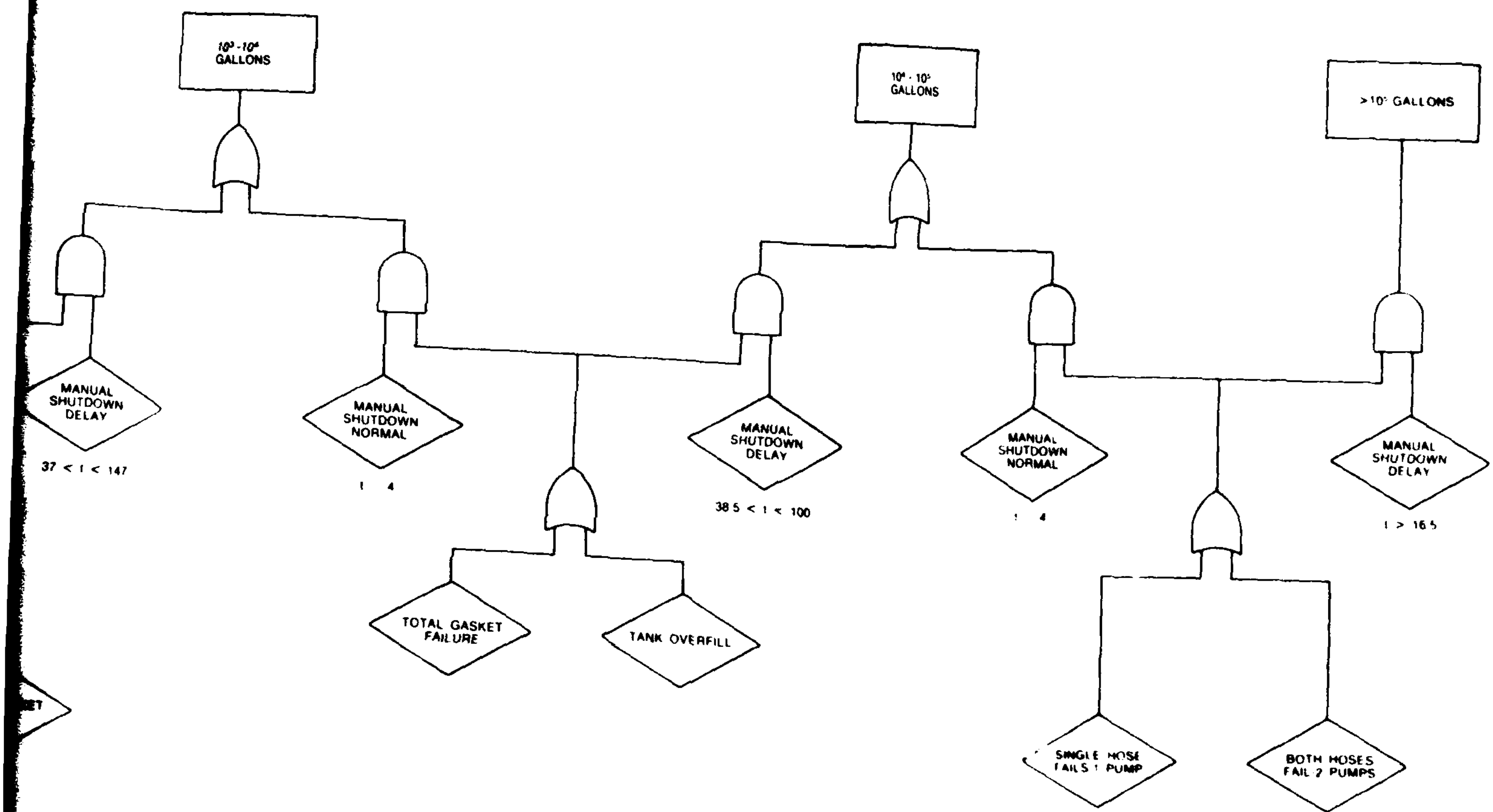
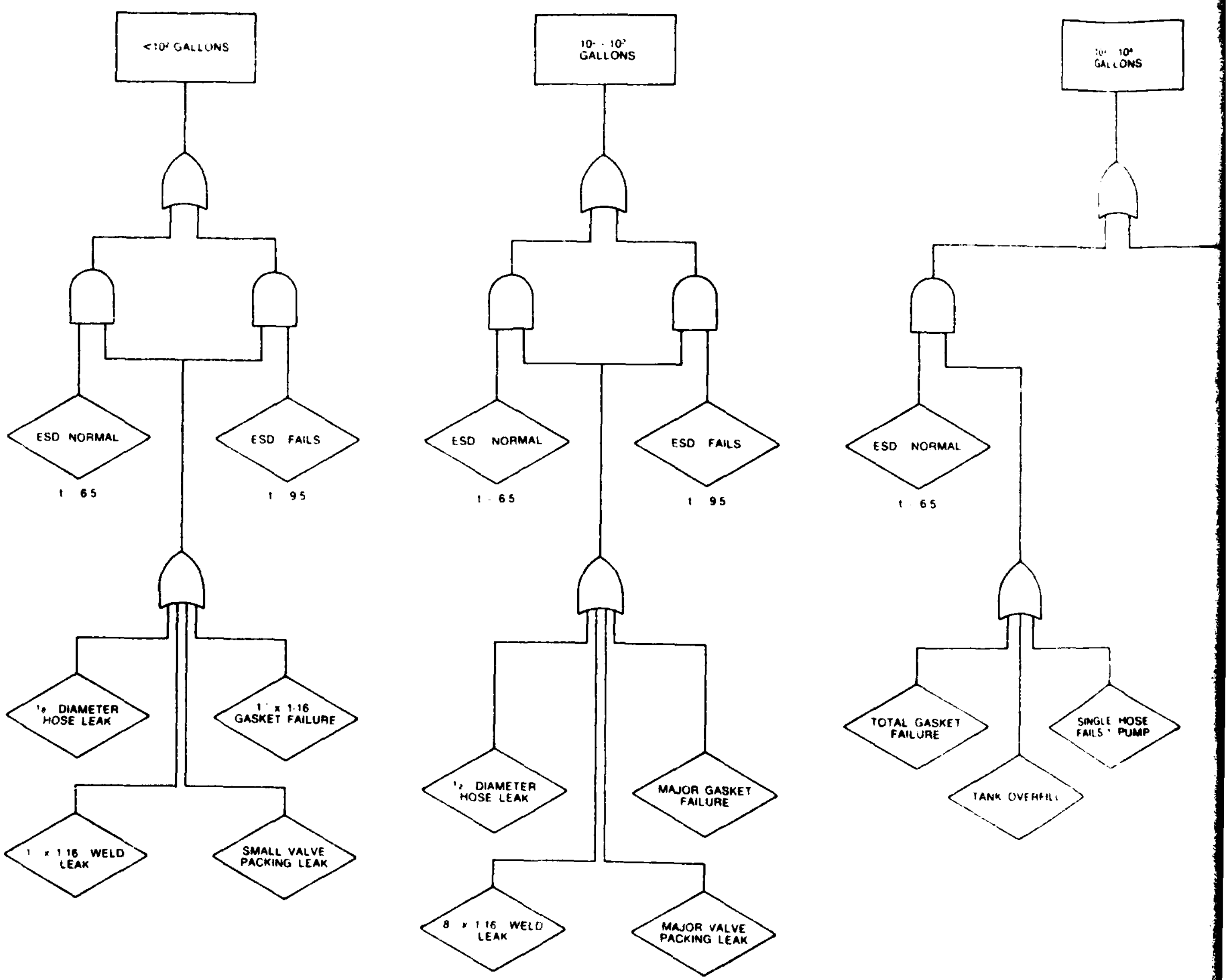


FIGURE 4-8

LOADING DECK SPILLS: MANUAL DETECTION WITH PATROL AND MANUAL SHUTDOWN



<10² GALLONS
ESD NORMAL
ESD FAILS
1 65
1 95
DIAMETER HOSE LEAK
GASKET FAILURE
LEAK
SMALL VALVE PACKING LEAK
GALLONS
ESD NORMAL
ESD FAILS
DIAMETER HOSE LEAK
MAJOR GASKET FAILURE
LEAK
MAJOR VALVE PACKING LEAK
GALLONS
ESD NORMAL
TOTAL GASKET FAILURE
PUMP

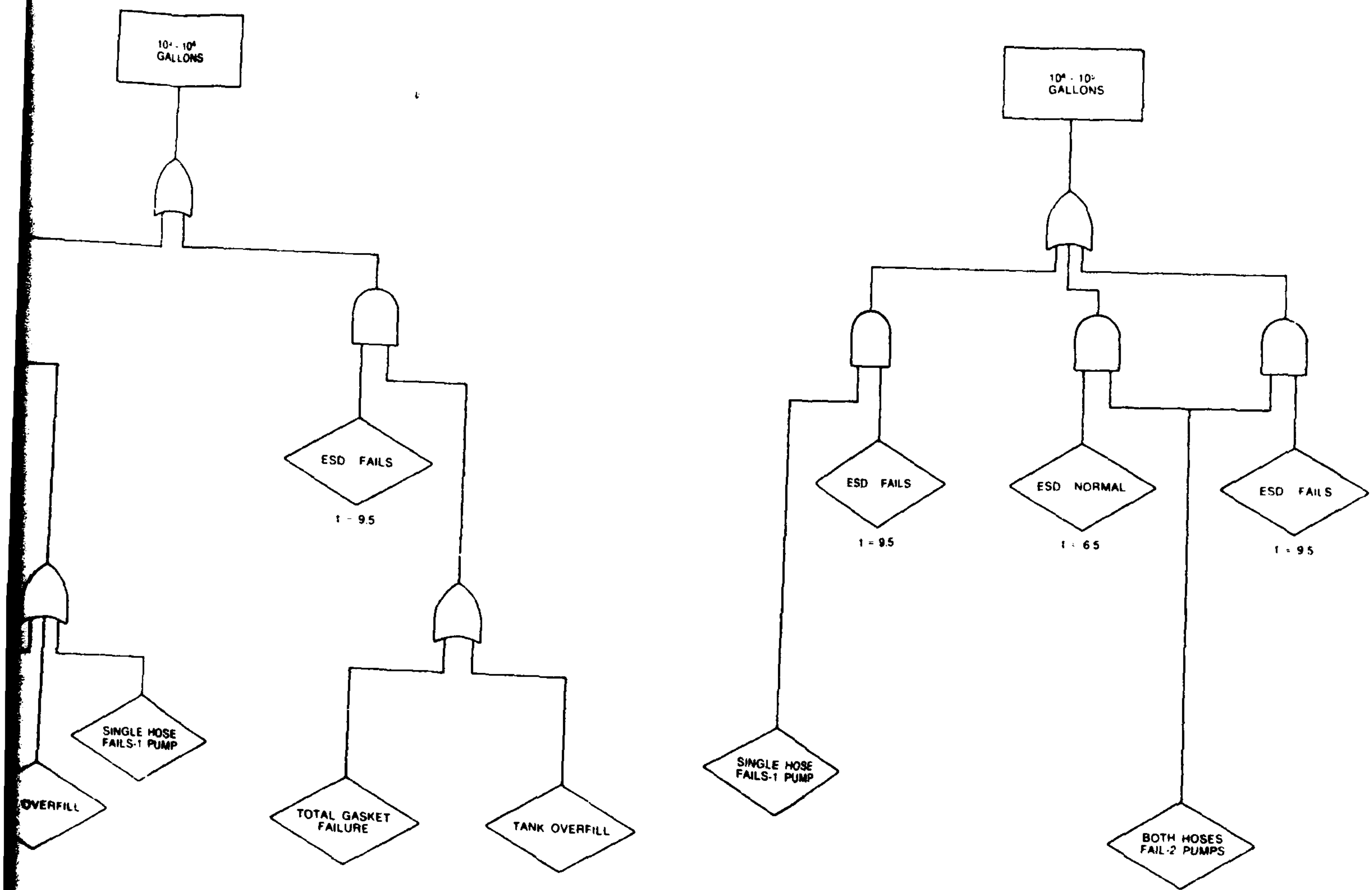


FIGURE 4-9

LOADING DECK SPILLS: MANUAL DETECTION WITH PATROL AND ESD

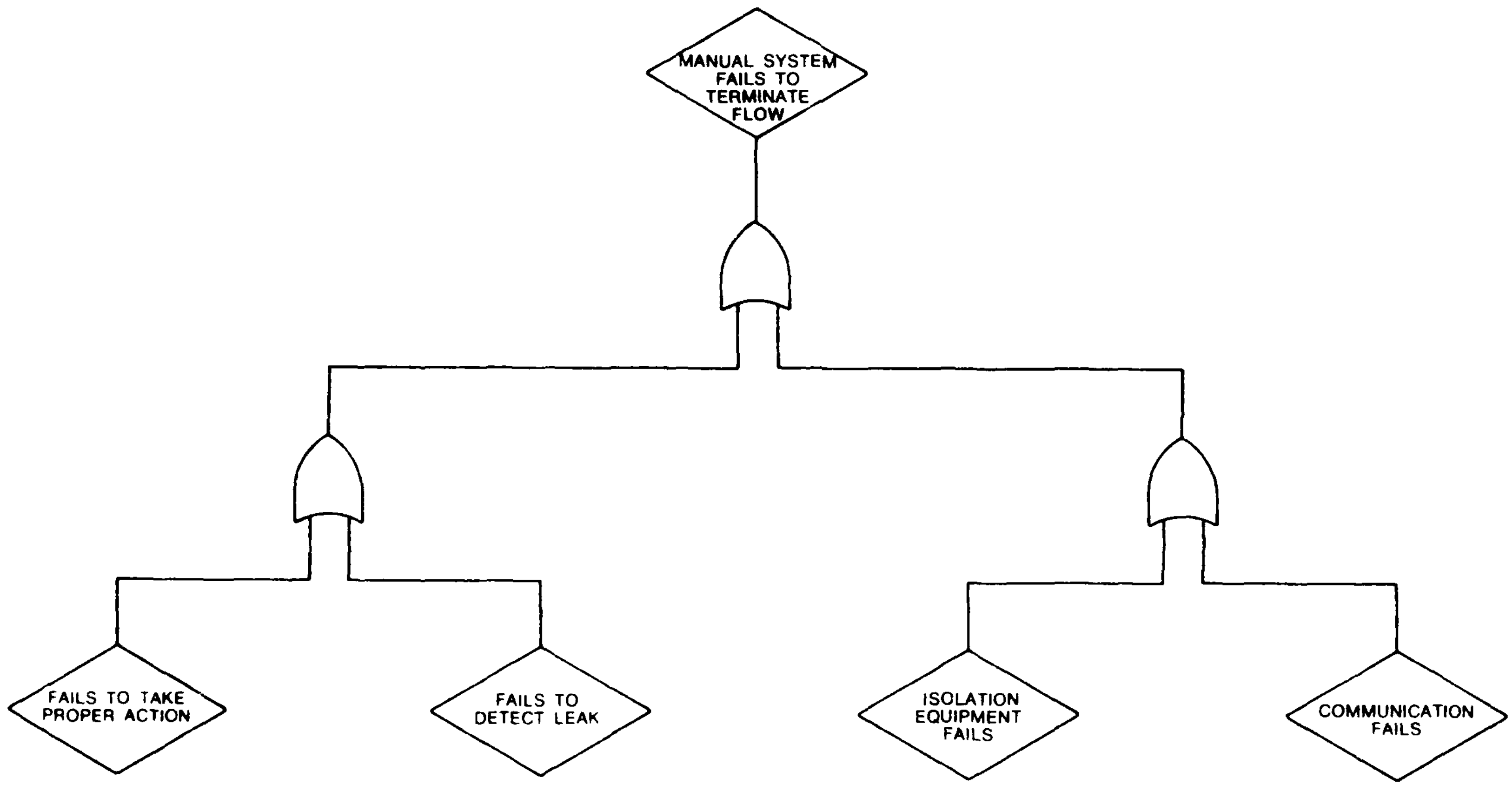


FIGURE 4-10

MANUAL SHUTDOWN SYSTEM FAILURE

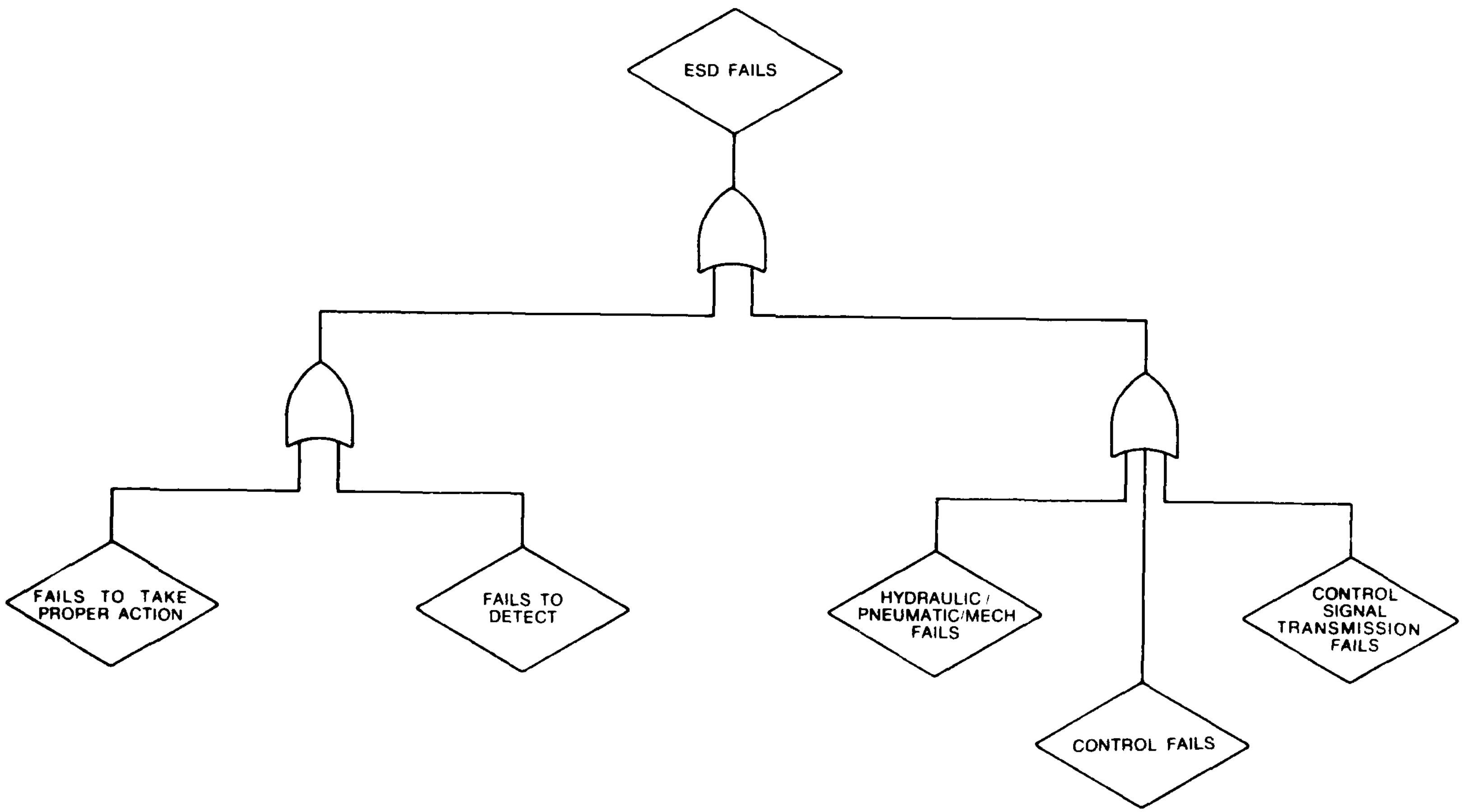


FIGURE 4-11

ESD FAILURE

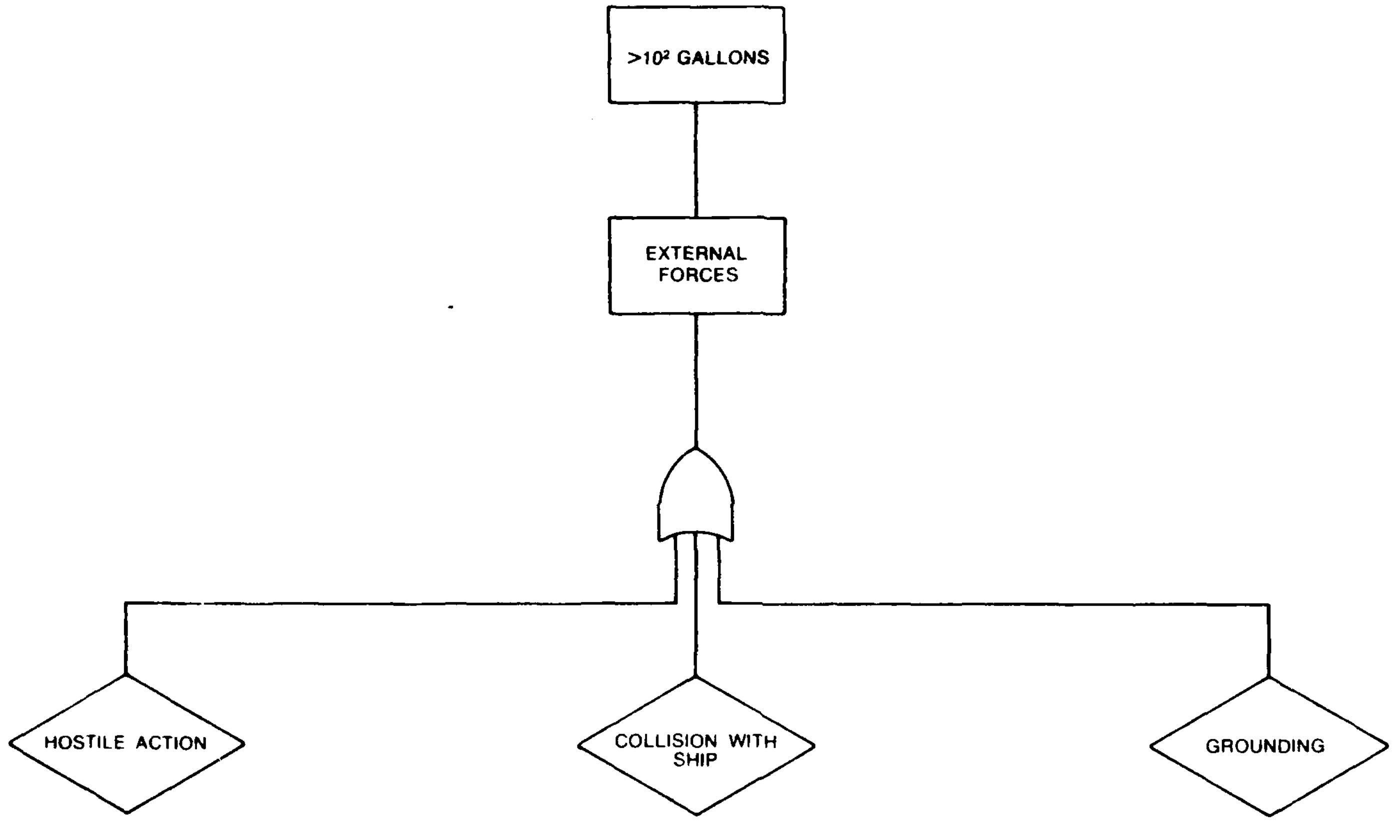


FIGURE 4-12

EXTERNAL FORCES SPILLS

SECTION 5

CONSEQUENCES OF CARGO SPILLS

In the previous section of this report the potential for spills of various volumes from the bulk transfer fuel system have been estimated. Even though the potential for a cargo spill of some size is very high the potential for ignition of that spill is considerably less. In this section of the report the potential for ignition of a spill is discussed, the consequences of a spill fire quantified and the reliability of the Taluga fire fighting systems discussed.

5.1 Ignition Sources

The potential for ignition subsequent to spills of a flammable fuel depends on many factors including the following: volatility of the cargo, amount of cargo spilled, location of ignition sources, environmental conditions at the time of the spill, and spill control procedures utilized by the crew.

Table 5-1 presents the flash ignition temperatures of the candidate cargos for the bulk fuel tanker. The lower the ignition temperature the easier the fuel is to ignite. Both motor gasoline and JP-4 have a flash ignition temperature that is below ambient in most climates. Thus, these fuels are easily ignited by common ignition sources; match, spark, etc. Diesel and JP-5 have flash temperatures above ambient and are thus more difficult to ignite than gasoline or JP-4. In fact, it is difficult to ignite diesel or JP-5 with a single match.

Many possible ignition sources exist for a cargo spill fire; but, the most common sources are: static electricity discharge; electrical wiring and equipment sparks; equiment hot spots; and the crew. Of the many possible causes of static discharges, the least recognized cause is due to the streaming potential of the flow of a low dielectric material through a nozzle. If vapor from a spill is ignited in an enclosed area; such as the engine room, crew quarters, or supply locker; an explosion can occur.

If a cargo release occurs due to either collision or hostile action the probability of ignition is very high. Ignition can be caused by the energetics of either the

TABLE 5-1

FLASH IGNITION TEMPERATURES

Fuel	Flash Temperature
Diesel (Arctic Formulation)	38°C (100°F)
DFM	60°C (140°F)
JP-5	35° - 63°C (95° to 145°F)
JP-4	-23° to -1°C (-10° to +30°F)
Motor Gas	-43°C (-46°F)

collision or hostile actions. Further, either of these release mechanisms could also result in shorting of electrical cables which would also result in ignition of spilled cargo.

If a shipboard spill does occur the potential for ignition can be reduced by covering the spill with foam. For fuels considered in this study, foam will retard the generation of vapors thereby reducing the potential for ignition of the spill.

In summary, we estimate the probabilities of ignition of a spill in a qualitative manner as follows:

Fuel Type	Release Mechanism	Ignition Probability
All fuels	Collision/hostile action	High
Motor gasoline, JP-4	Piping and or hose release	50/50
Diesel, JP-5	Piping and or hose release	Low

5.2 Consequences of Spill Fires

For any fuel spill, there is a possibility that the spill will be ignited. The resultant fire could damage or destroy almost any part of the tanker that it contacts directly and could cause structural damage, equipment failures, secondary fires, etc., due to the thermal radiation from the fire on objects outside the flame.

A pseudo-theoretical approach based on radiative heat transfer has been developed to calculate heat radiation levels downwind of a fuel fire. The radiant heat flux from the fire can be computed from the radiant flux at the flame surface and the view factor between the flame and the exposed object. This is given by:

$$q = F\tau q_{sm}(1 - e^{-bD})$$

where:
- q = the incident radiant flux at any point
- q_{sm} = maximum surface flux of the flame for a large fire
- F = the geometric view factor
- D = fire diameter

b = extinction coefficient related to the absorption of radiation within the flame
τ = atmospheric transmissivity

The maximum surface flux for gasoline, diesel and jet fuel were approximated to be 35,000 BTU/hr-ft^2, 27,000 BTU/hr-ft^2 and 35,000 BTU/hr-ft^2, respectively. The extinction coefficients for each fuel were estimated to be 0.055 ft^{-1}. The view factor is dependent on the size of the fire, the relative orientation and distance between the fire and the exposed object. Detailed calculation models for view factors are available from literature sources.(10, 19)

Flame size is the combination of pool diameter (or side length of a rectangular diked area) and flame height. The flame height can be calculated from the equation given by Thomas(25):

$$L = 42(D)[Q/\rho_a(gD)^{1/2}]^{0.61}$$

where:
- L = length (height) of the flame
- D = diameter of the pool
- Q = mass burning rate
- ρ_a = air density
- g = gravitational acceleration

Linear burning rates for gasoline, diesel and jet fuel are all approximately 0.25 in/min.

Large buoyant flames can be strongly affected by winds. The wind tilts the flame with an angle that can be computed by the equation given by Welker and Sliepcevich(27):

$$\frac{\tan\Theta}{\cos\Theta} = 3.2\left(\frac{Du\rho_a}{\mu_a}\right)^{0.07}\left(\frac{u^2}{Dg}\right)^{0.7}\left(\frac{\rho_g}{\rho_a}\right)^{-0.6}$$

where:
- Θ = angle of tilt of the flame (measured from the vertical)
- D = flame diameter
- u = wind speed
- μ_a = viscosity of air
- ρ_a = density of air
- ρ_g = density of fuel vapors
- g = gravitational acceleration

Water vapor in the air reduces the incident radiant flux on a target by absorbing some of the radiant energy. The amount by which the flux is reduced depends on the relative humidity and the separation distance between the target and the flame. Therefore, the incident radiant flux on a given point from a given fire decreases as the relative humidity increases.

Energy Analysts has built into its fire radiation computer program all of these factors. Table 5-2 is a reproduction of the typical computer output for the fire radiation program. The symbols in the table identify the following:

XPLUS - Fires exposed to wind become eliptical in shape at their base. XPLUS is computed to assure that the fire radiation calculations start outside the fire as the geometry of the fire base changes with wind speeds

TARGET HEIGHT - Height of target relative to the base of the flame

XT(FT) - Separation distance from target to center of fire

Q(VERT) - Computed radiant heat flux on a vertical target

Q(MAX) - Computed radiant heat flux for a target rotated such that it receives the maximum possible radiant heating

Q ACTUAL - Q(MAX) corrected for humidity in the air

The footnote on the table indicates the target is at or near the edge of the fire and could be engulfed in the fire.

Fire radiation calculations have been made for the following spill conditions:

- Drip pan spill
- Deck spill - area underneath the pipe connections along the side of the tanker. This area is 250 ft x 7 ft and is a natural accumulation area created by the slope of the deck.
- Spill on IMODCO - SPM confined to drainage channel
- Various sizes of spills on water and deck

```
*                                                               *
*     ENERGY ANALYSTS, INC. COMPUTER ANALYSIS                   *
*     P.O. BOX 1508                                             *
*     2001 PRIESTLEY AVE                                        *
*     NORMAN, OKLAHOMA 73069                                    *
*     TEL. 405-321-5778                                         *
*                                                               *
*          FIRE-RAD FIRE RADIATION MODEL                        *
*                                                               *
*****************************************************************
```

```
---- CASE NUMBER     1 -----
----  WSPEED=0., TY= 0.

     INPUT DATA :               FUEL IS          GASOLINE
                          WIND SPEED IS       0.  FT/SEC
                                              0.  MPH
                      FLAME DIAMETER IS    120.0 FT
                       TARGET HEIGHT IS       0.  FT
                           MASS FLUX IS   .01520 LB/SEC-FT-FT
                           MASS RATE IS   171.91 LB/SEC
                 PIPE/POOL DIAMETER IS   120.00 FT
                    PERCENT HUMIDITY IS    25.00
                 AMBIENT TEMPERATURE IS    70.00 DEG F
      BLACK BODY FLAME TEMPERATURE IS   1610.0 DEG F

     COMPUTED DATA : BENDING ANGLE IS       0.  DEGREES
                        FLAME HEIGHT IS    147.3 FT
                        SURFACE FLUX IS  34952.4 BTU/HR-FT*FT
               PARTIAL PRESSURE H2O IS    .0063 ATM
                          MINIMUM XT IS     72.0 FT
```

XT (FT)	Q(VERT)	Q(HORIZ)	Q(MAX)	QACTUAL	THETAMAX (DEGREES)
	(*************	BTU/HR-FT*FT		************)	
84.00	12431.4*	8496.7*	15057.7	12751.6	34.4
126.00	7969.6	4405.2	9106.0	7469.7	28.9
189.00	4636.3	1907.6	5013.4	3961.5	22.4
283.50	2385.3	675.1	2479.0	1875.4	15.8
425.25	1116.7	209.4	1136.2	819.7	10.6
637.87	502.5	61.8	506.3	347.8	7.0
956.81	222.3	17.9	223.1	146.0	4.6
1435.22	98.0	5.2	98.1	61.3	3.0

TABLE 5-2

FIRE RADIATION MODEL COMPUTER OUTPUT

A relative humidity of 50 percent and winds of 0, 20 and 40 MPH have been used in the calculations.

5.2.1 Drip Pan Fires

Figures 5-1, 5-2, and 5-3 present heat radiation profiles downwind of fuel spill fires confined to drip pan #4. Drip pan #4 is the largest drip pan on the Taluga and as such represents a worst case drip pan fire. The figures present heat radiation fluxes as a function of separation distance from the center of the drip pan. The following presents fire radiation hazards as a function of heat radiation flux level.

- 1600 BTU/hr-ft^2: bare skin exposed to this heating level will sustain second degree burns in 30 seconds
- 4000 BTU/hr-ft^2: minimum for ignition of most combustible materials
- 10,000 BTU/hr-ft^2: potential equipment damage.

It is evident from Figures 5-1, 5-2 and 5-3 that the radiant heat flux for this drip pan fire exceeds 1600 BTU/hr only when one is within 30 feet of the pan. Thus, fire crews could approach and fight this fire without major risk. Further, only equipment directly involved in this fire or within a few feet of the pan would sustain fire damage. These results show that drip pan fires can be readily attacked and fought by fire fighting crews.

5.2.2 Deck Spill Fire

Figures 5-4, 5-5, and 5-6 present fire radiation profiles for a cargo spill onto the deck and confined to an area 250 feet long x 7 feet wide. The deck of the Taluga under the cargo pipeway is raised and sloped such that any spill will flow away from the center of the main deck to both port and starboard. Any liquid spill would be confined to a strip 7 feet wide by 250 feet long with the outer edge bounded by the gunwale. There are three small scuppers along the gunwale. However, these scuppers are not adequate to prevent spill accumulation given any realistic spill on the deck. The inner edge of the spill area is a 1 to 1 1/2-inch step which initiates the raised portion of the deck. It is evident from the figures and Table 5-3 that the hazard zone for personnel is well in excess of 100 feet and thus, this

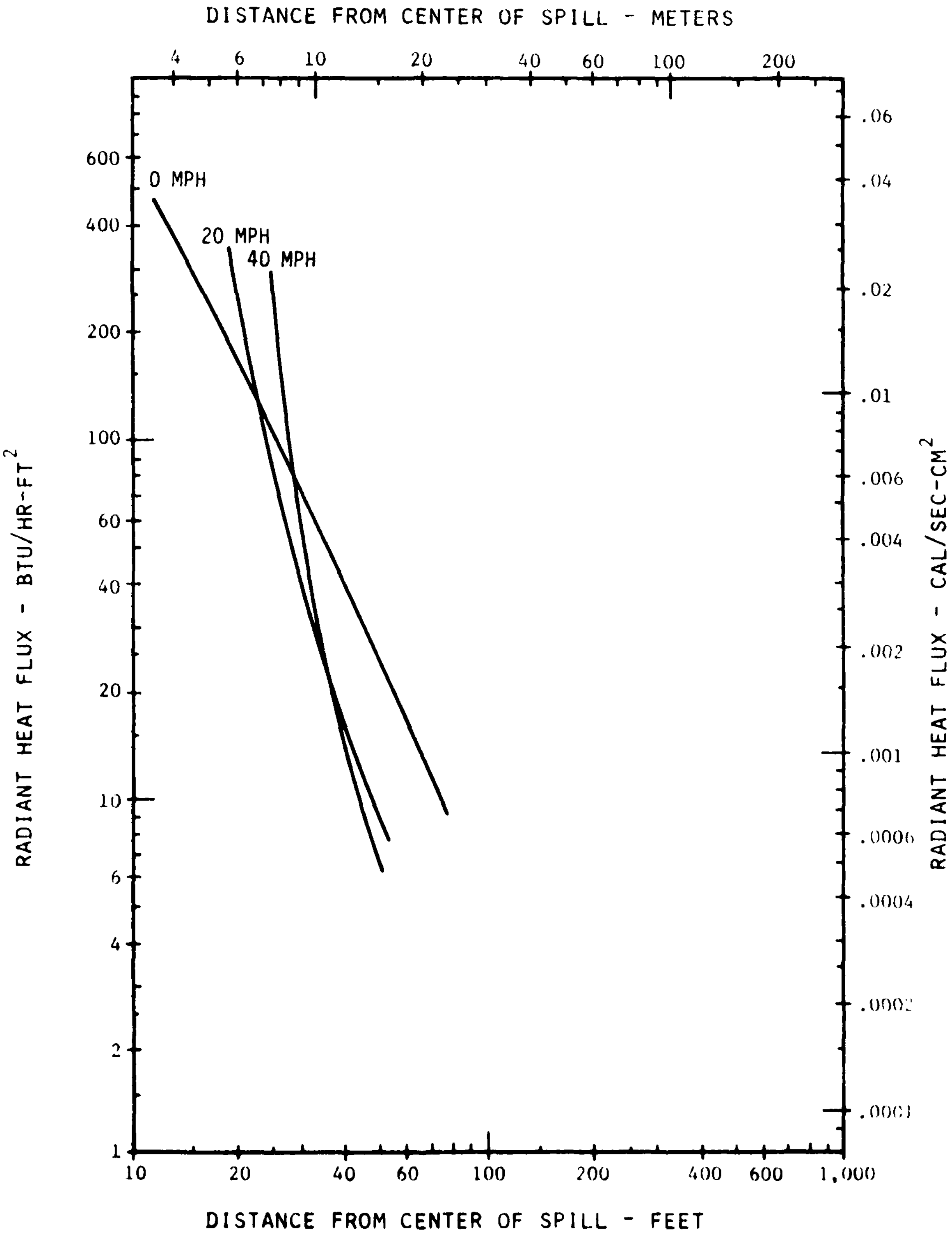


FIGURE 5-1. RADIANT FLUX PROFILE OF DRIP PAN #4 GASOLINE FIRE

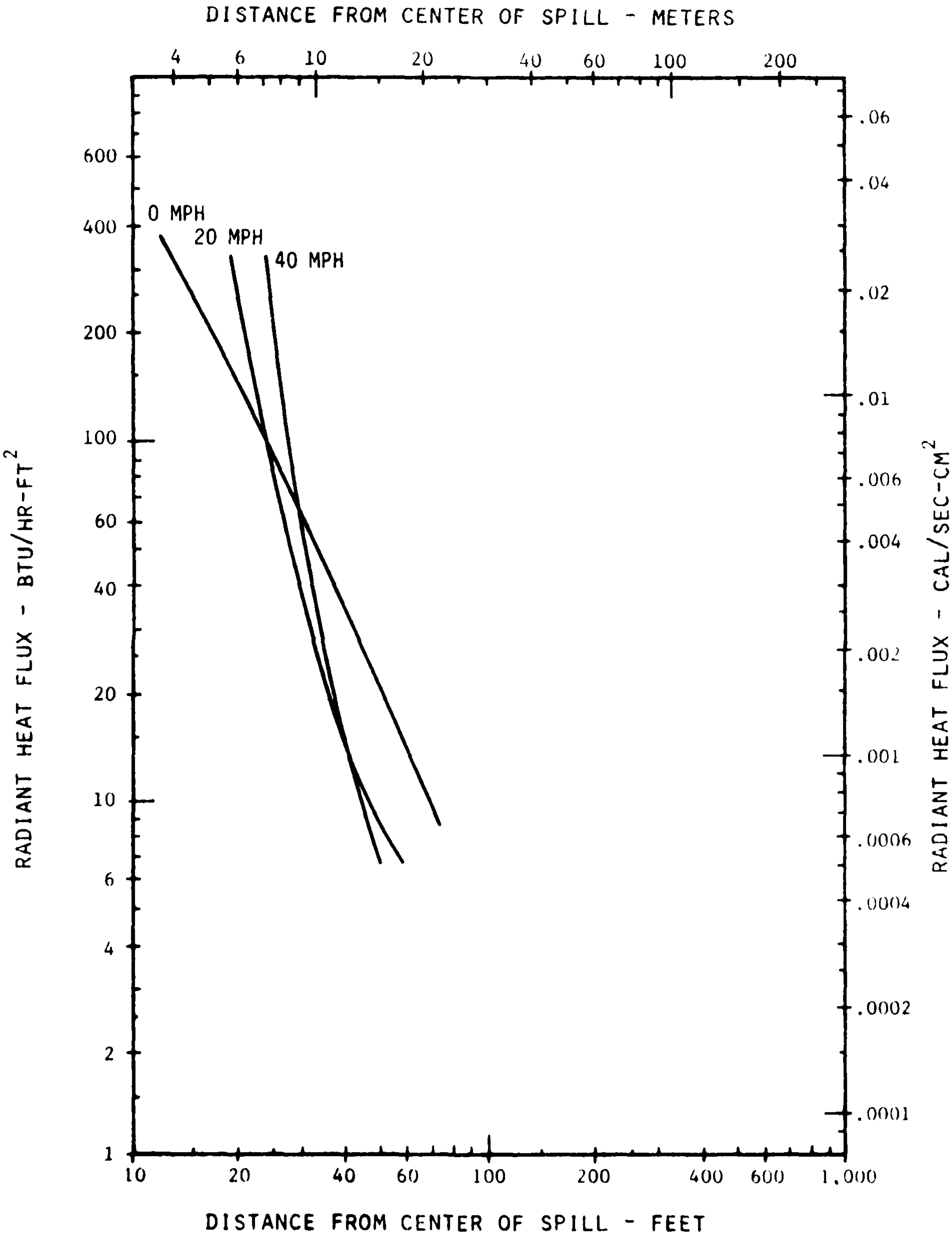


FIGURE 5-2. RADIANT FLUX PROFILE OF DRIP PAN #4 DIESEL FIRE

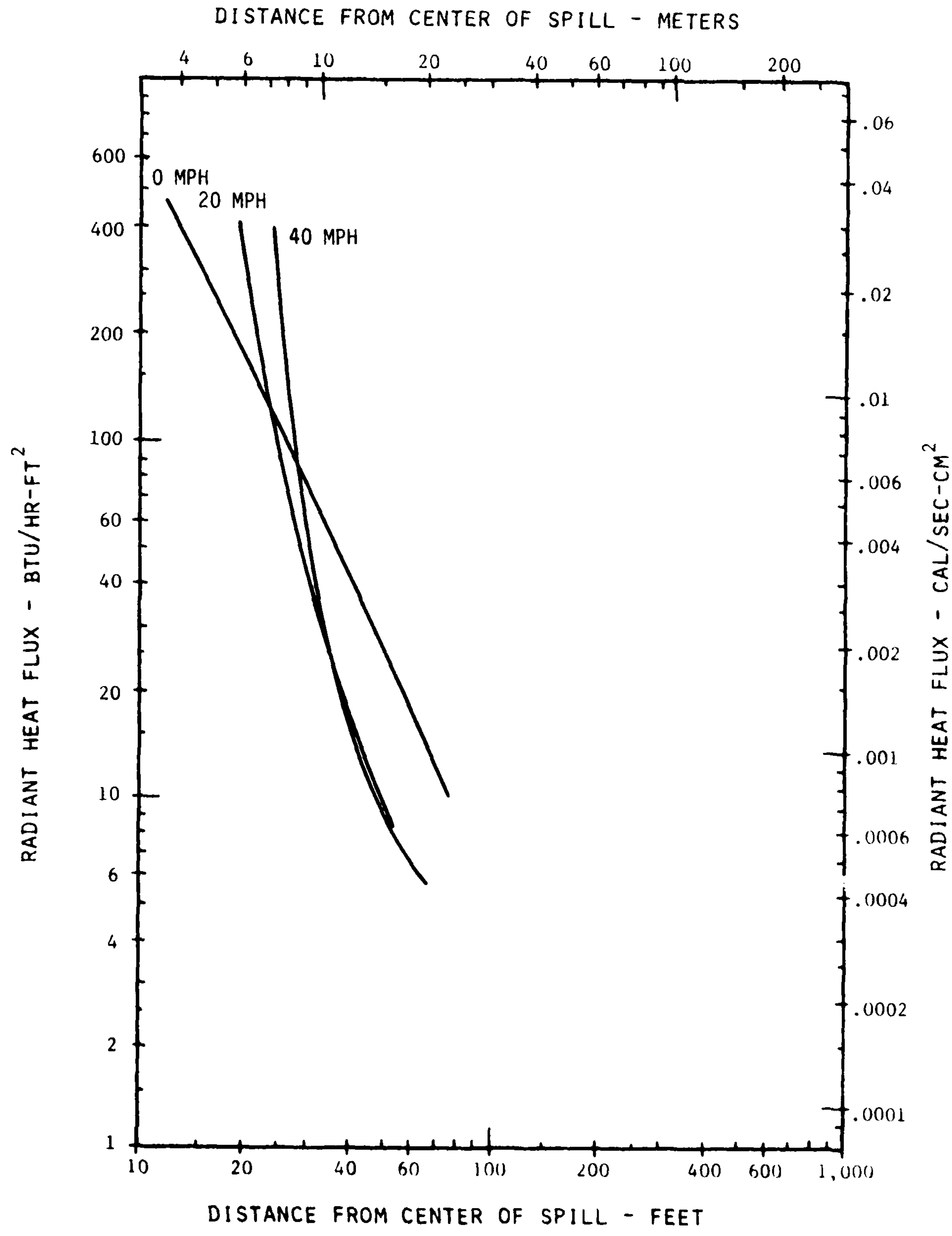


FIGURE 5-3. RADIANT FLUX PROFILE OF DRIP PAN #4 JET FUEL FIRE

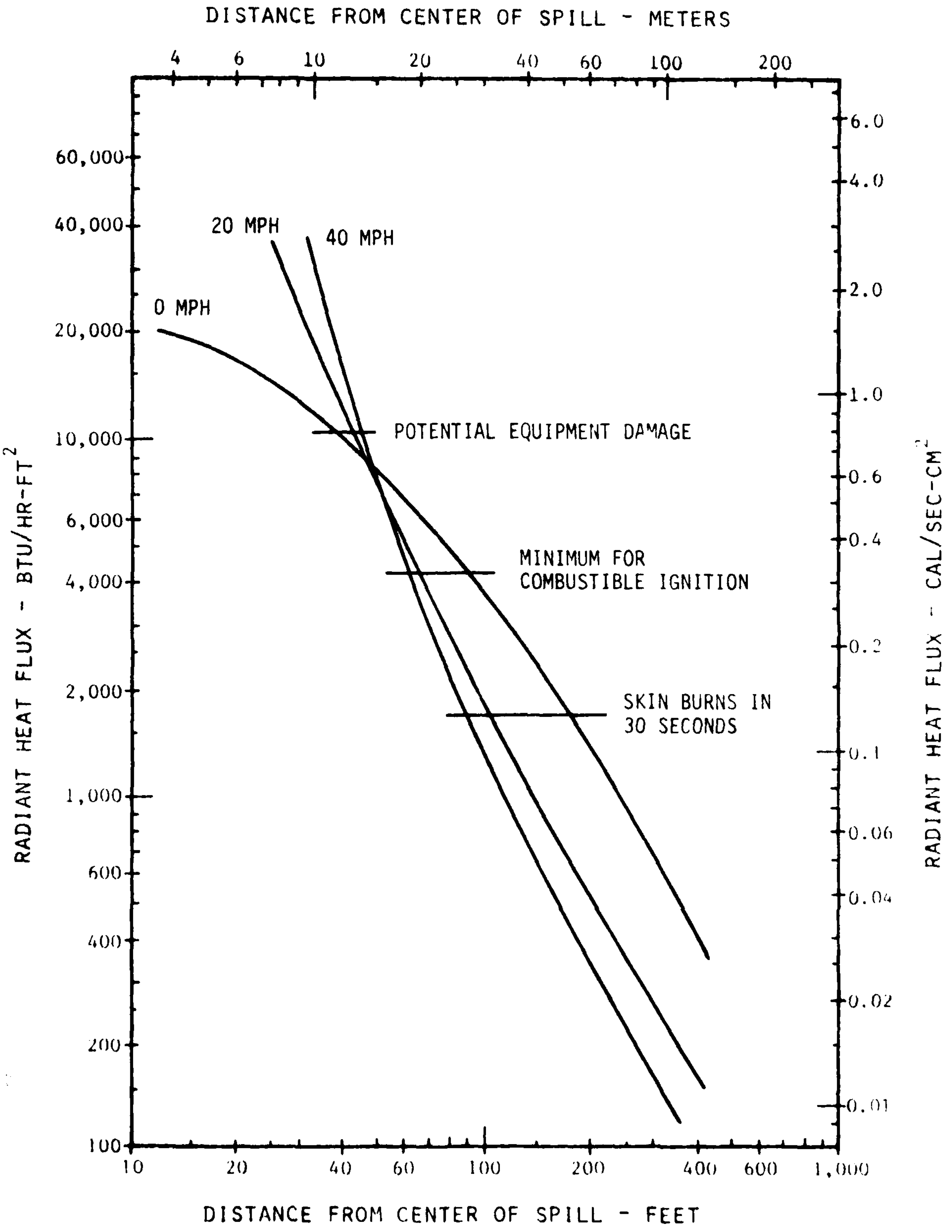


FIGURE 5-4. RADIANT FLUX PROFILE OF GASOLINE DECK FIRES

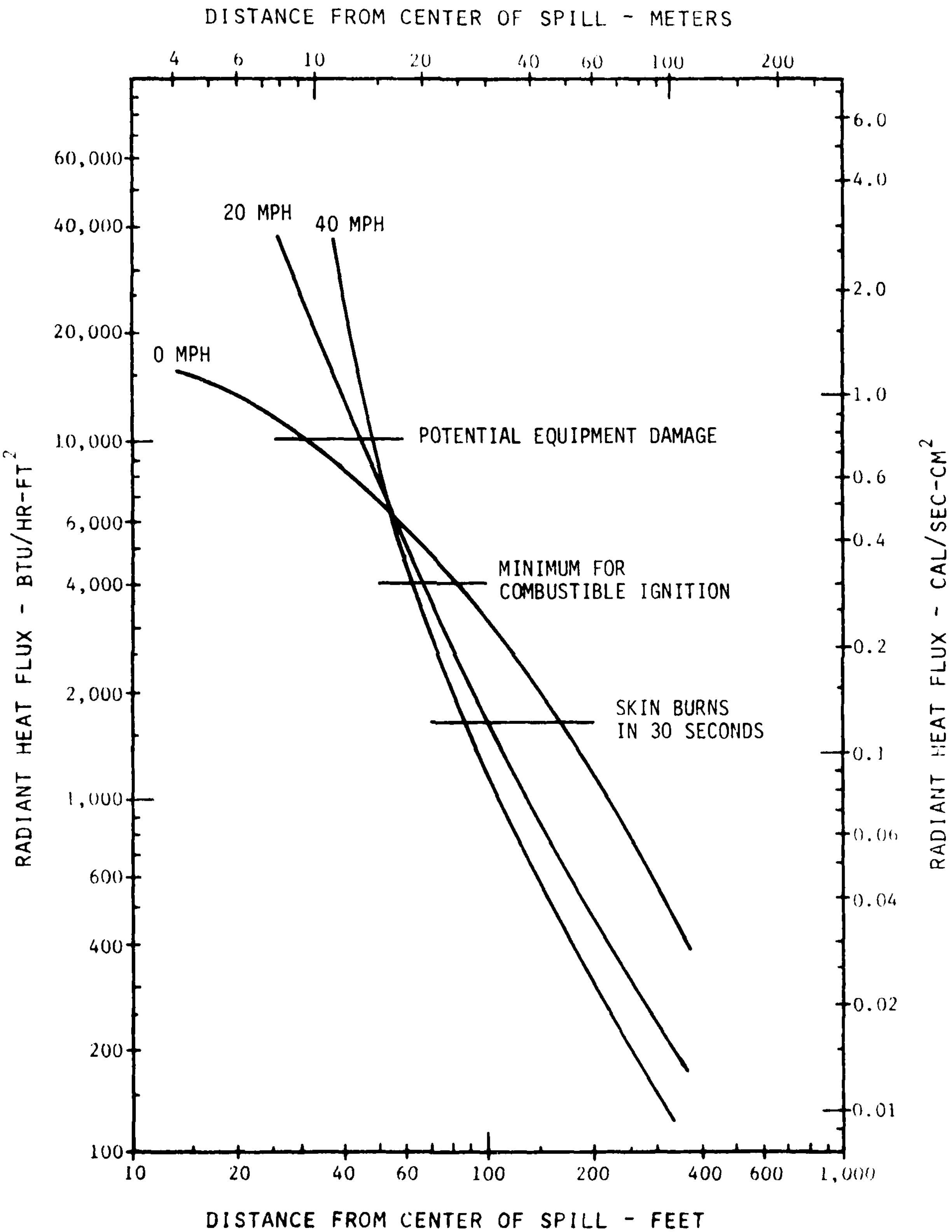
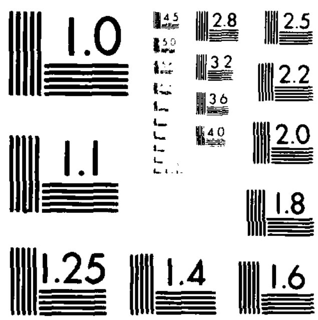


FIGURE 5-5. RADIANT FLUX PROFILE OF DIESEL FUEL DECK FIRES



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

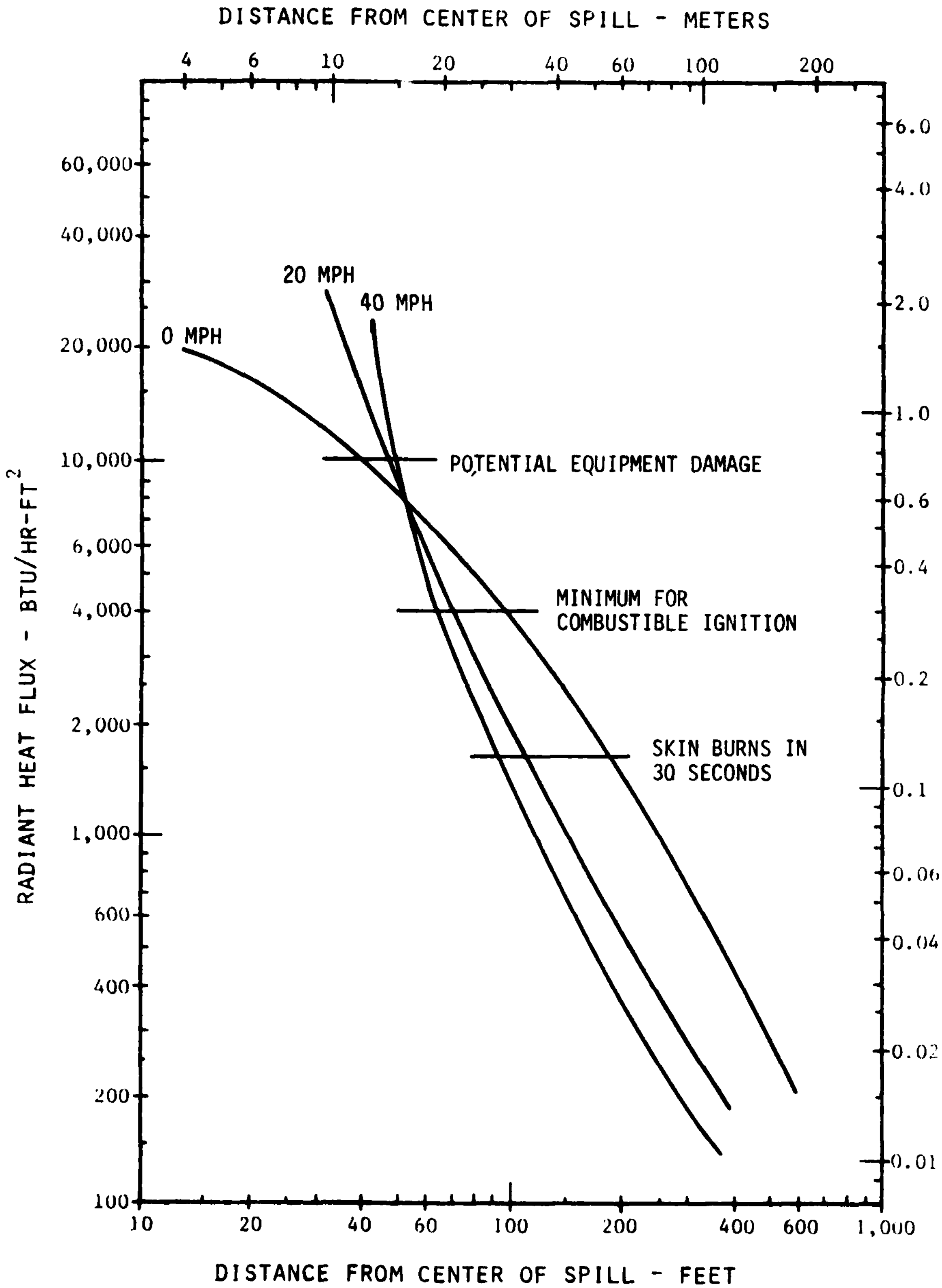


FIGURE 5-6. RADIANT FLUX PROFILE OF JET FUEL DECK FIRES

TABLE 5.3

HEAT RADIATION ISOPLETHS FOR DECK SPILL FIRES

	$1,600\ BTU/hr\text{-}ft^2$	$4,000\ BTU/hr\text{-}ft^2$	$10,000\ BTU/hr\text{-}ft^2$
Gasoline			
0MPH	172 ft	88 ft	37 ft
20MPH	100 ft	63 ft	41 ft
40MPH	86 ft	59 ft	44 ft
Diesel			
0MPH	155 ft	77 ft	29 ft
20MPH	98 ft	64 ft	42 ft
40MPH	83 ft	58 ft	46 ft
JP-4			
0MPH	175 ft	42 ft	37 ft
20MPH	106 ft	66 ft	46 ft
40MPH	90 ft	60 ft	47 ft

size fire would be very difficult to fight manually. Additionally, wood structures within about 60 feet of the fire could ignite (wind speed 0 MPH).

5.2.3 Fires Confined to IMODCO SPM Drain Channel

Figures 5-7, 5-8, and 5-9 show fire radiation profiles for fires confined to the SPM drainage channel. Table 5-4 shows distances to key heat fluxes from the center of the channel. Given the distances to the 1600 BTU/hr-ft^2 profile it would be difficult for personnel to approach a cargo spill fire on the SPM from the downwind side. It is important to realize that if the fuel is not drained from the channel a fire in the channel could burn up to 48 minutes. This fire would do significant structural damage to the portion of the SPM above the water line.

5.2.4 Fires Subsequent to Spills on Water and Deck

Heat radiation profiles subsequent to cargo spills onto water have been calculated for spill diameters of 50, 100, 200 and 500 feet. The calculations for 50 and 100 feet diameter fires can also be used for deck fires. A 50 foot diameter fire would be slightly larger than one centerline cargo compartment fire aboard the Taluga. A 100 foot diameter fire would be equal to two cargo tanks fully involved in fire.

Table 5-5 presents key radiant heat flux isopleth distances for targets at grade. From the table it can be seen that personnel will have difficulty manually fighting one of these larger fires. Further, any of these fires would do significant structural damage to the ship.

5.3 Reliability of Taluga Fire Fighting Systems

Because of the potential fire hazards associated with operation of the offshore bulk fuel system storage tanker, an analysis of the capability of the installed fire fighting systems was performed.

5.3.1 Fire Water System

A fault tree analysis of the events that would result in the loss of all fire main water is shown in Figure 5-10 for the USNS Taluga. This analysis shows that the estimated

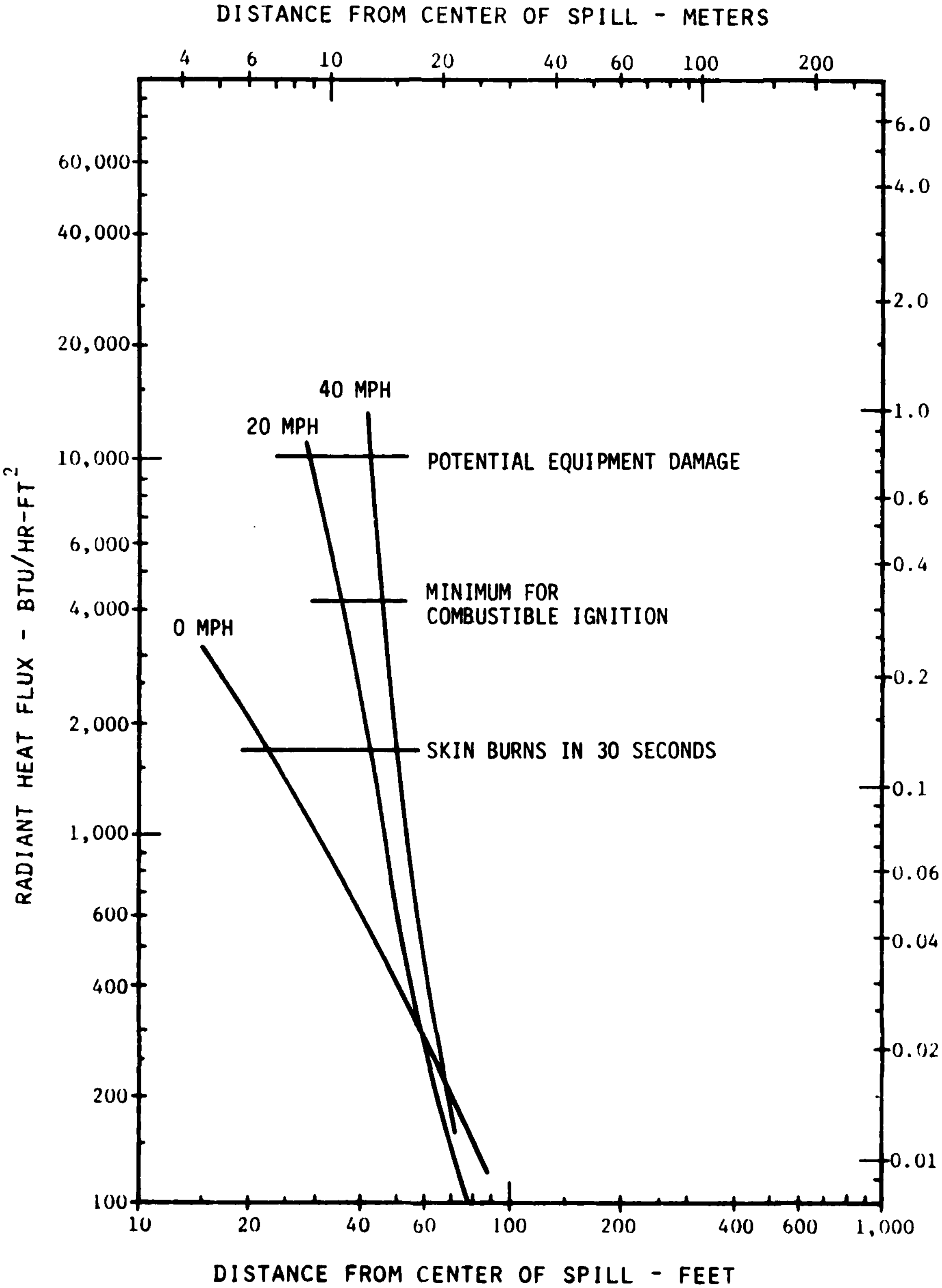


FIGURE 5-7. RADIANT FLUX PROFILE OF IMODCO-SPM GASOLINE FIRE

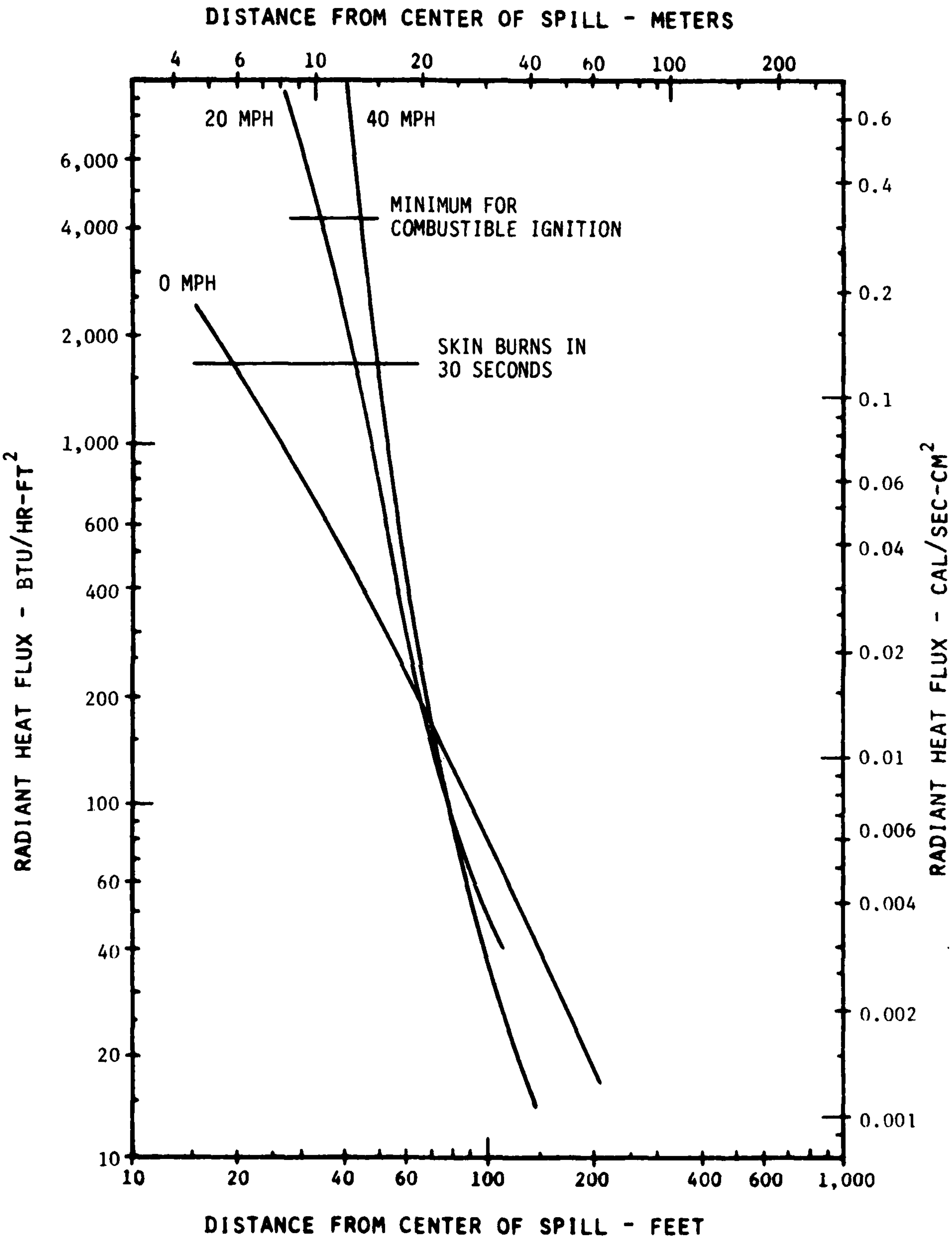


FIGURE 5-8. RADIANT FLUX PROFILE OF IMODCO-SPM DIESEL FUEL FIRES

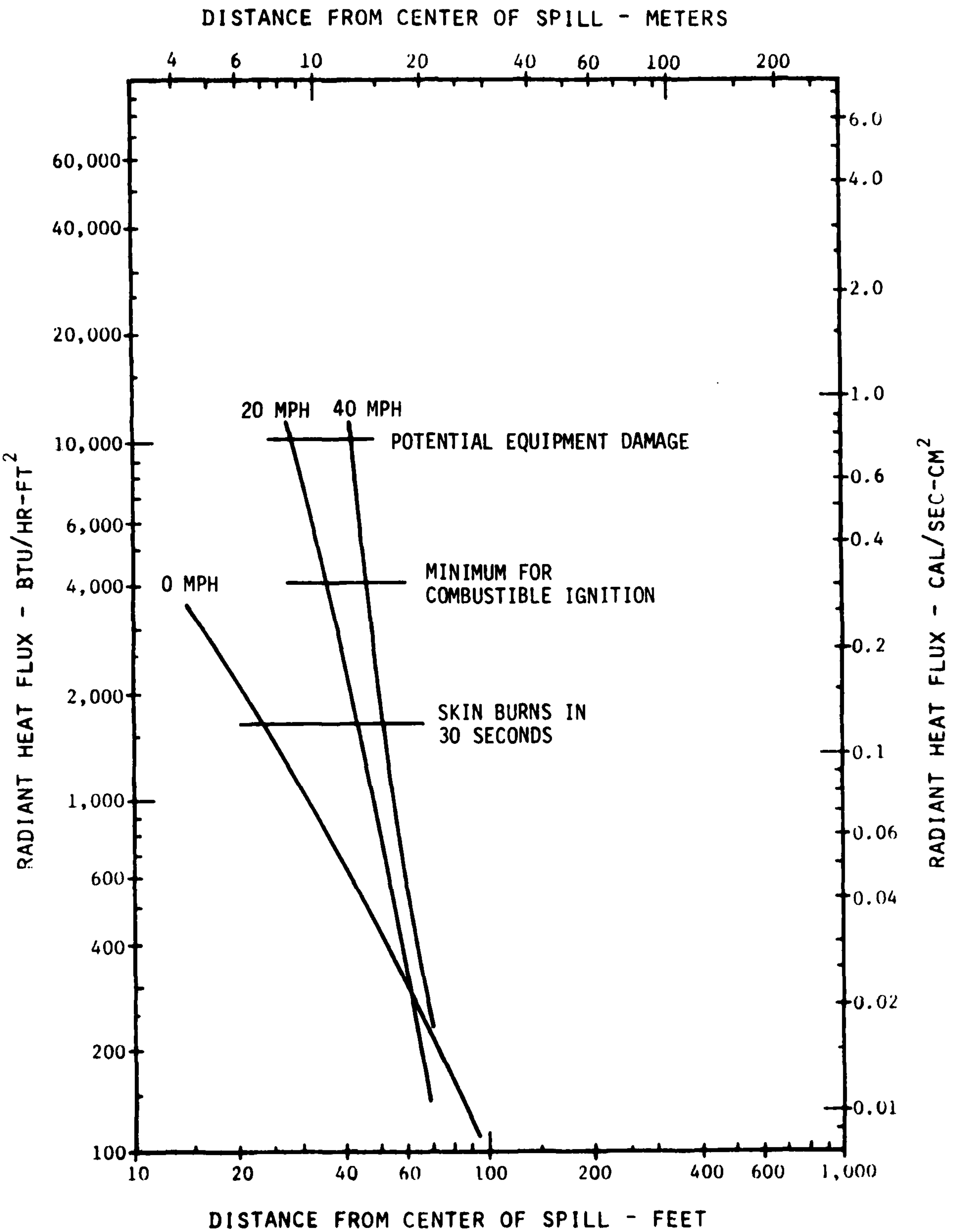
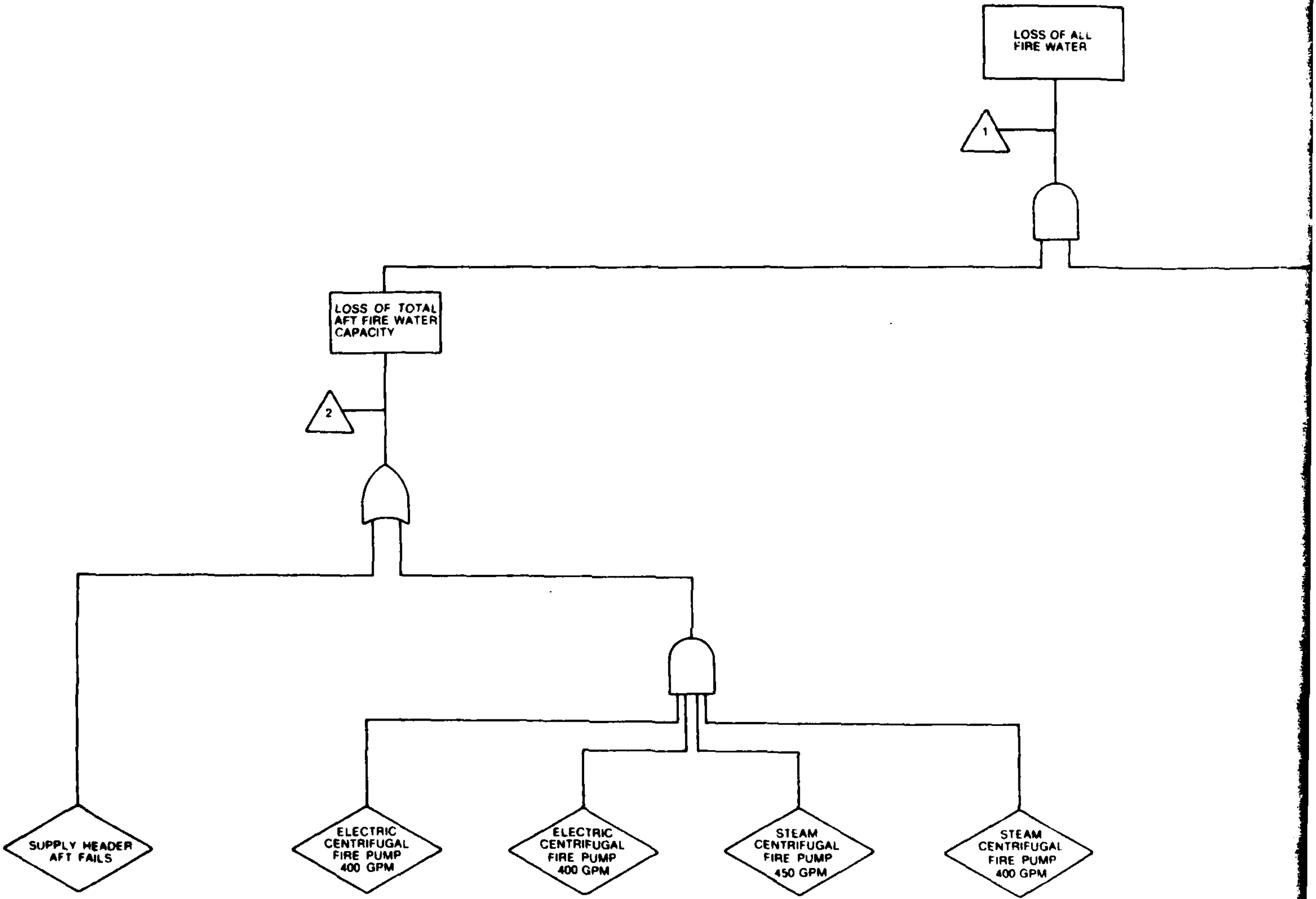


FIGURE 5-9. RADIANT FLUX PROFILE OF IMODCO-SPM JET FUEL FIRES



LOSS OF ALL FIRE WATER
1
LOSS OF TOTAL AFT FIRE WATER CAPACITY
2
SUPPLY HEADER AFT FAILS
ELECTRIC CENTRIFUGAL FIRE PUMP 400 GPM
ELECTRIC CENTRIFUGAL FIRE PUMP 400 GPM
STEAM CENTRIFUGAL FIRE PUMP 450 GPM
STEAM CENTRIFUGAL FIRE PUMP 400 GPM

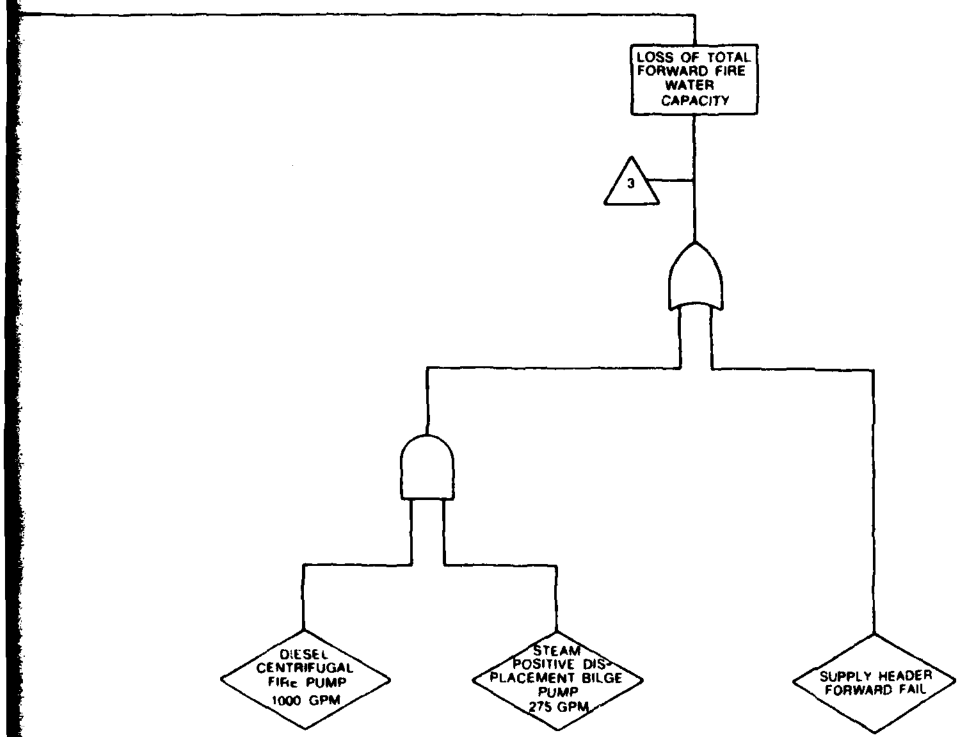


FIGURE 5-10

LOSS OF ALL FIRE WATER

2

TABLE 5.4

HEAT RADIATION ISOPLETHS FOR IMODCO - SPM SPILL FIRES

	1,600 BTU/hr-ft^2	4,000 BTU/hr-ft^2	10,000 BTU/hr-ft^2
Gasoline			
0MPH	23 ft	-	-
20MPH	40 ft	34 ft	28 ft
40MPH	48 ft	43 ft	40 ft
Diesel			
0MPH	19 ft	-	-
20MPH	41 ft	33 ft	-
40MPH	47 ft	42 ft	-
JP-4			
0MPH	22 ft	-	-
20MPH	41 ft	35 ft	27 ft
40MPH	48 ft	44 ft	39 ft

TABLE 5.5

HEAT RADIATION ISOPLETHS (ft) OF SPILLS ON WATER (FOR TARGET HEIGHT = 0ft)

	1,600 BTU/hr-ft^2			4,000 BTU/hr-ft^2			10,000 BTU/hr-ft^2		
Gasoline	0MPH	20MPH	40MPH	0MPH	20MPH	40MPH	0MPH	20MPH	40MPH
Dia. 50 ft	135	175	200	79	140	180	41	110	160
100 ft	250	320	340	150	240	290	80	180	250
200 ft	450	550	580	270	410	480	160	290	410
500 ft	1000	1120	1180	630	750	900	360	540	740
Diesel Fuel									
Dia. 50 ft	123	175	195	69	138	170	32	94	140
100 ft	230	310	340	130	235	285	66	155	225
200 ft	410	540	580	240	400	470	130	260	360
500 ft	880	1080	1200	540	740	940	190	450	660
Jet Fuel									
Dia. 50 ft	135	180	200	80	145	180	41	110	160
100 ft	265	320	350	155	250	295	82	175	250
200 ft	470	560	600	280	430	510	160	300	410
500 ft	1000	1200	1200	630	820	960	360	540	730

probability of the loss of all fire main water is 5.8 x 10^{-11} an extremely low value. This means that short of losing the entire tanker it is virtually impossible to suffer a total loss of fire main water. This result is not too surprising since there is a great deal of redundancy in the source of supply and in the supply paths.

Because the emergency diesel driven fire pump has a capacity of 1000 gpm a fault tree analysis was conducted for the events that cause a reduction in the fire main capacity to less than or equal to 1000 gpm. Figure 5-11 shows these events and their relationships. The probability of this reduction in fire main capacity is 4.1 x 10^{-8}. While this value is three orders of magnitude greater than the complete loss of fire water event it is still an extremely improbable event.

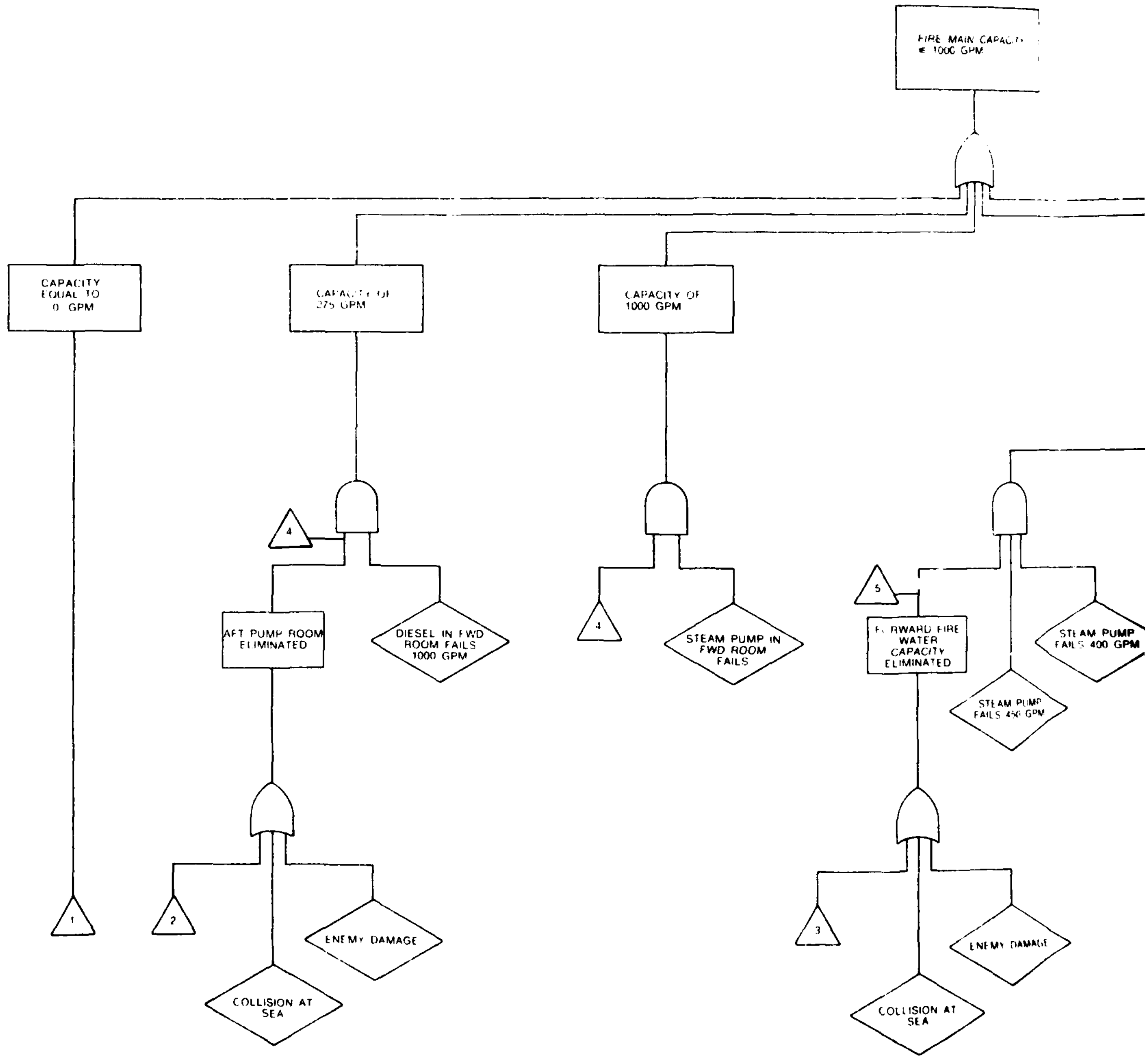
We can therefore conclude that the primary fire fighting system on the USNS Taluga, i.e., the firewater system, is a very reliable system.

5.3.2 Foam Systems

Because fire fighting foam is an exceptionally important system for combatting hydrocarbon fuel fires, an analysis of the events that produce a degradation in the capability of the AFFF system was conducted. The fault trees for no output from the AFFF system and reduced output from the AFFF system are shown in Figures 5-12 and 5-13, respectively. We should note that these are demand related events and therefore, we are interested in the probability that there will be no output from the AFFF when it is called upon to function. The probability of this event is estimated to be approximately .003. This implies that there are three chances in one thousand that the AFFF system will fail to work on demand. Similarly, the chances are approximately two in ten thousand that the AFFF system will respond at a reduced output when it is called upon to function.

5.3.3 Dry Chemical Unit

Since the dry chemical system, PKP fixed extinguishers, serves as a backup and supplement to the hydrocarbon fuel fire fighting system, an analysis of system failure was also performed. The fault tree for this sysem is shown in Figure 5-14. The probability that this system fails on demand is approximately .01.



FIRE MAIN CAPACITY ≤ 1000 GPM
CAPACITY EQUAL TO 0 GPM
CAPACITY OF 275 GPM
CAPACITY OF 1000 GPM
4
AFT PUMP ROOM ELIMINATED
DIESEL IN FWD ROOM FAILS 1000 GPM
4
STEAM PUMP IN FWD ROOM FAILS
5
FORWARD FIRE WATER CAPACITY ELIMINATED
STEAM PUMP FAILS 450 GPM
STEAM PUMP FAILS 400 GPM
1
2
ENEMY DAMAGE
COLLISION AT SEA
3
ENEMY DAMAGE
COLLISION AT SEA

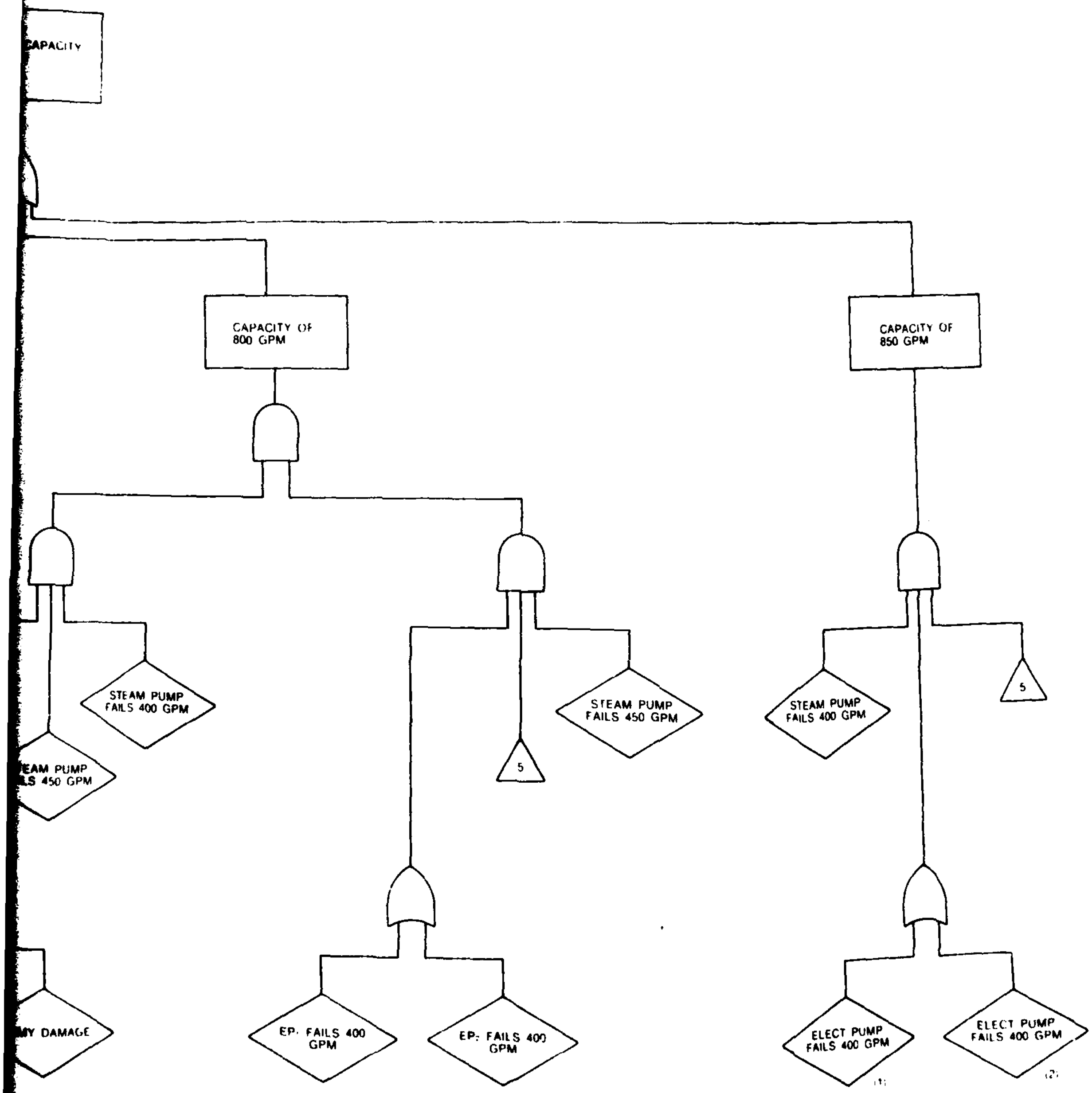


FIGURE 5-11

FIRE MAIN CAPACITY ≤ 1000 GPM

2

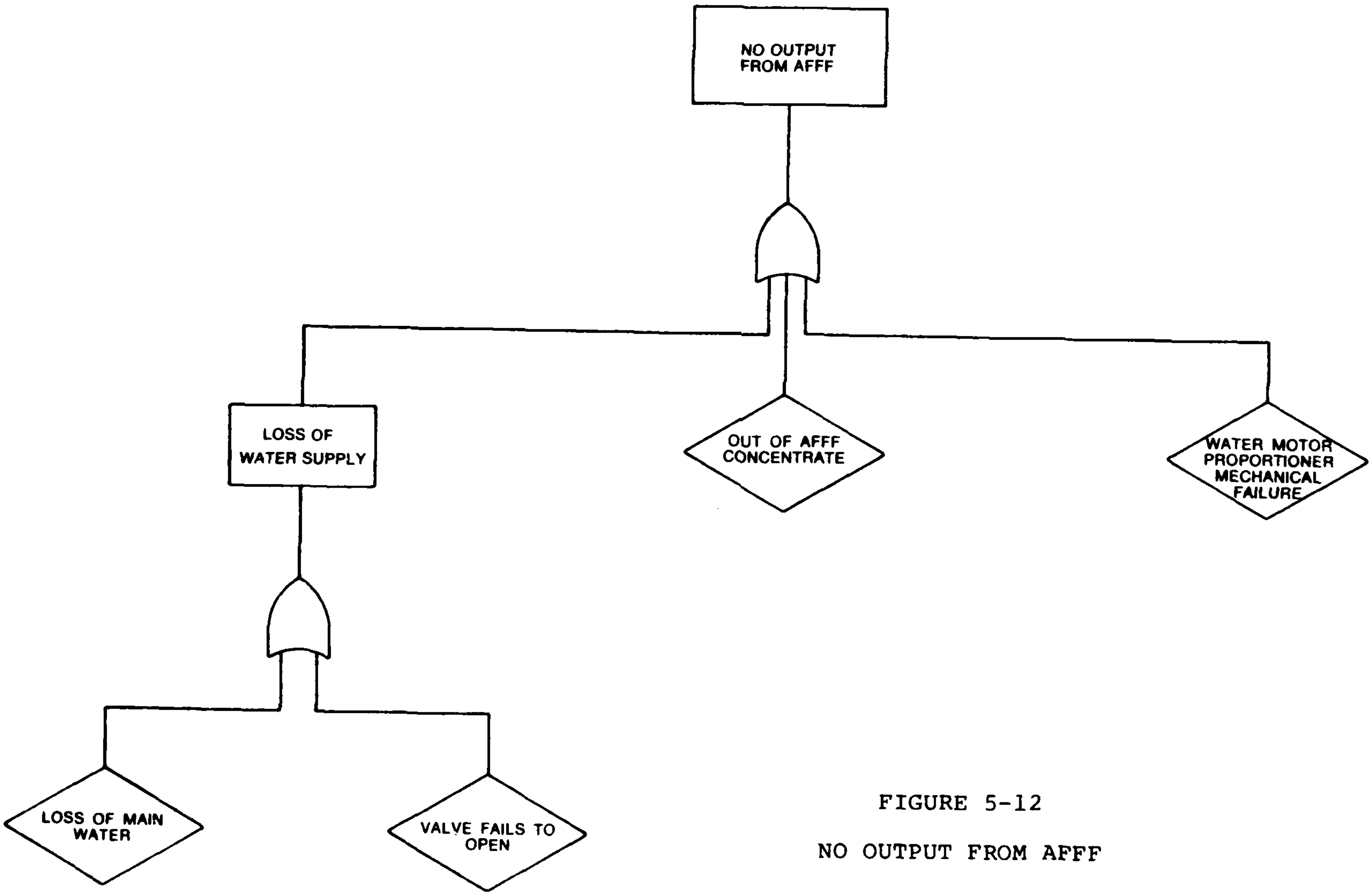


FIGURE 5-12

NO OUTPUT FROM AFFF

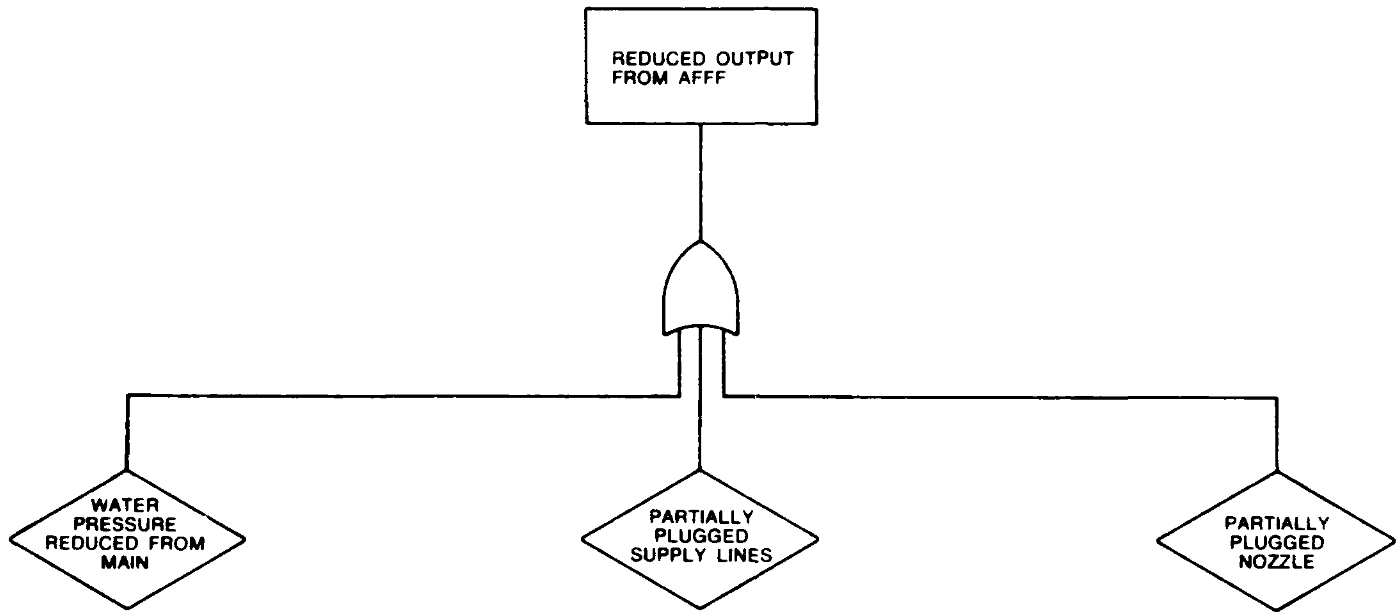
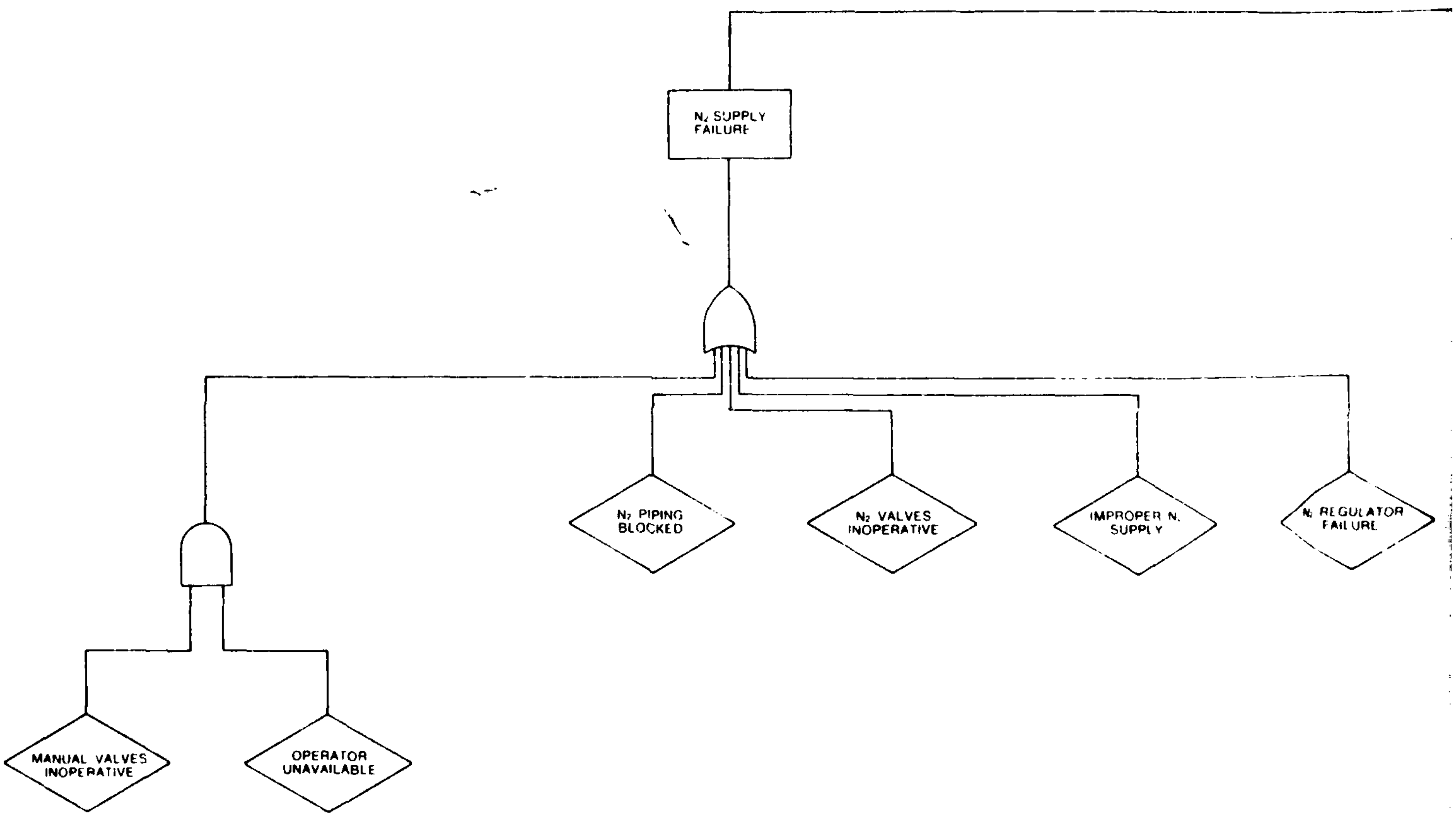


FIGURE 5-13

REDUCED OUTPUT FROM AFFF



N_2 SUPPLY FAILURE
N_2 PIPING BLOCKED
N_2 VALVES INOPERATIVE
IMPROPER N_2 SUPPLY
N_2 REGULATOR FAILURE
MANUAL VALVES INOPERATIVE
OPERATOR UNAVAILABLE

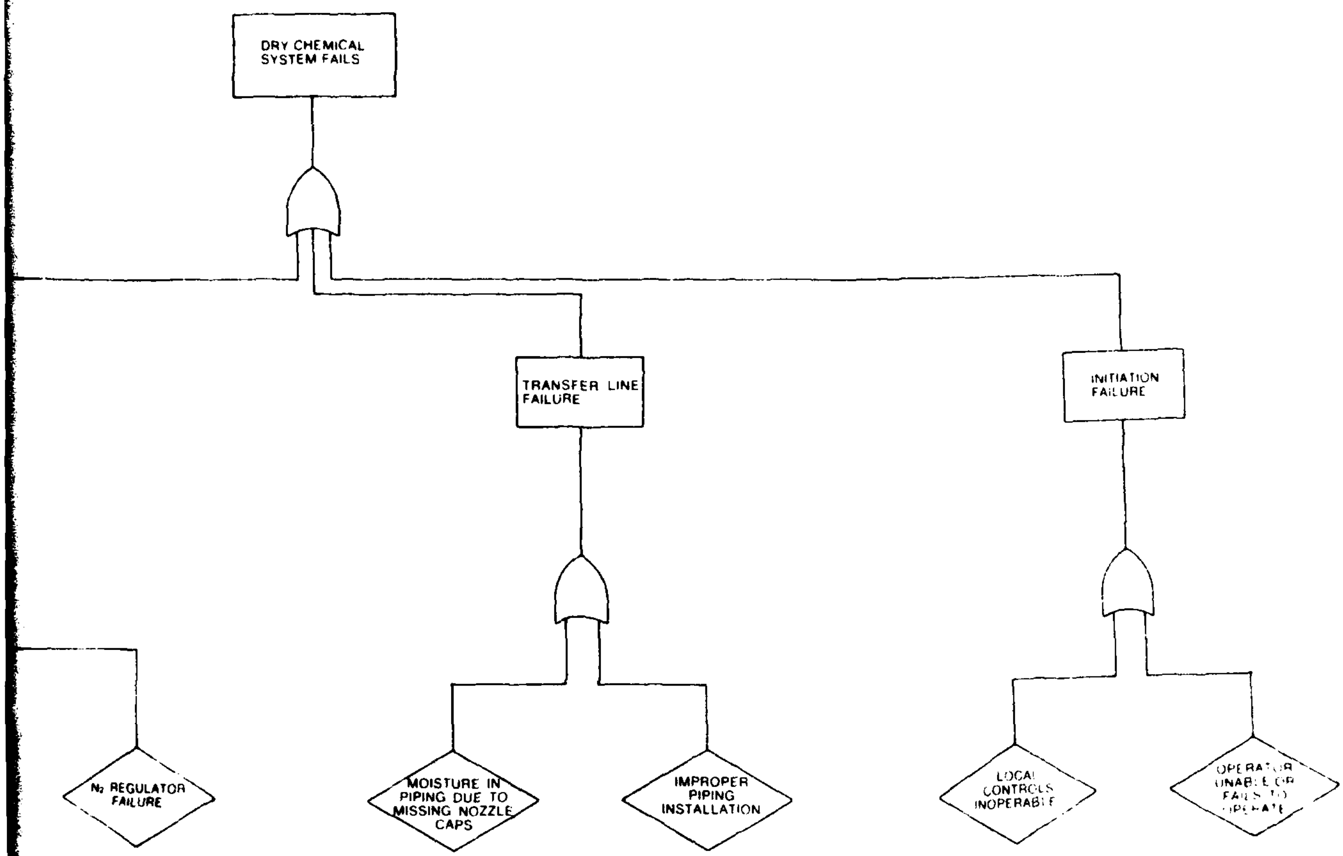


FIGURE 5-14

DRY CHEMICAL SYSTEMS FAILS

2

5.3.4 Carbon Dioxide Inerting System

The carbon dioxide smothering system for the pump room was analyzed for the events leading to a complete failure. The resulting fault tree is shown in Figure 5-15. The probability of a complete failure of this system on demand is .0017.

5.3.5 Summary of Fire Fighting Systems Reliability

In summary, the installed fire water system on the USNS Taluga is an extremely reliable system. This is primarily a result of the system redundancy in supply and flowpaths. The AFFF system is much less reliable by several orders of magnitude. This is primarily due to the performance of the water motor proportioner when used in the AFFF system and the chances of having an inadequate supply of foam concentrate. At this time the Navy is having an electric driven AFFF concentrate proportioner designed to correct this deficiency. The installed dry chemical system is not a very reliable system. Aboard ship failure of large dry chemical systems have occurred fairly frequently. The CO_2 smothering system is a very reliable system with the primary reason for system failure being the failure of personnel to activate the system.

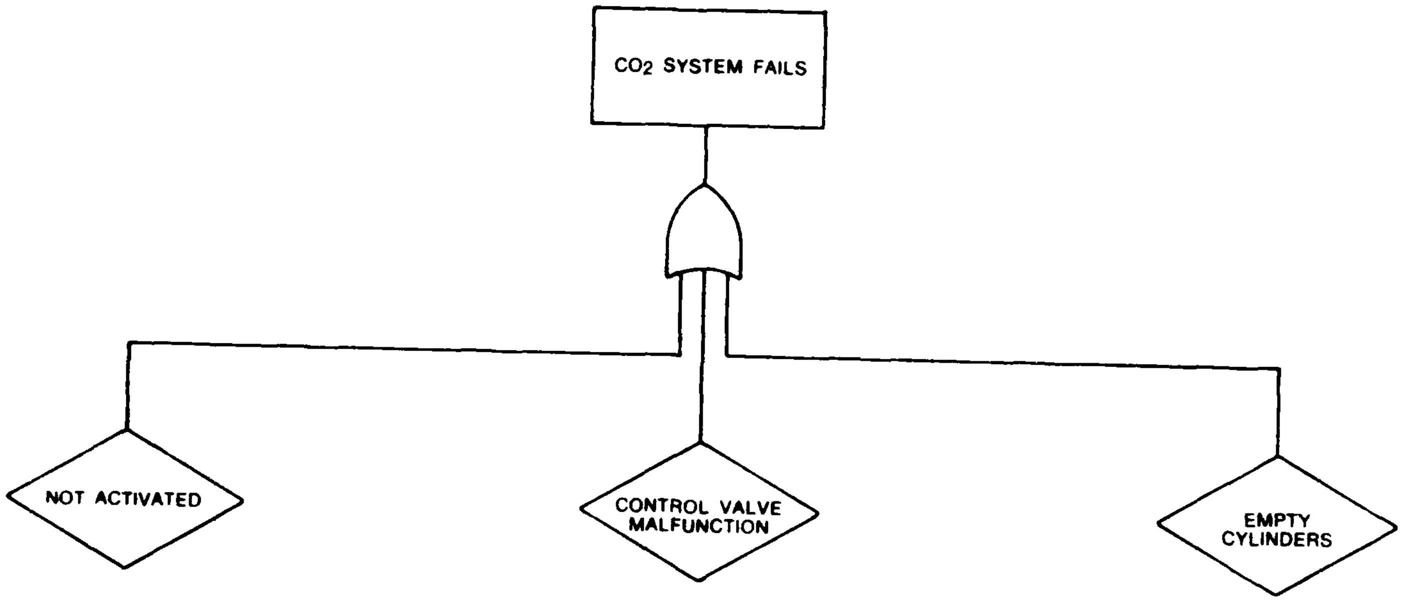


FIGURE 5-15

CO_2 SYSTEM FAILS

SECTION 6

EVALUATION OF EXISTING EQUIPMENT AND PROCEDURES

6.1 Manpower Considerations

Historically, fire fighting aboard ship in the U. S. Navy has been a manpower intensive operation. This situation exists when fires are being fought by repair parties from a general quarters condition or if the at-sea or in-port fire party is involved during a more relaxed condition of readiness.

This system of combating fires is a reasonable and effective system when used on ships that have a large number of personnel assigned to the crew. This large crew size is usually predicated on the personnel requirements necessary to meet the operational mission of the ship.

Additionally, the control of damage to a ship which includes fire fighting is considered to be an all hands responsibility in the U. S. Navy. Consequently, all Navy personnel receive training in the basics of recognition, reporting, and fighting of shipboard fires. A number of the crew from each department on the ship will have attended formal Navy fire fighting school and specially trained crew members of the Engineering Department will be assigned to key positions in the shipboard fire fighting organization.

A typical shipboard fire party will consist of the following:

1. Fire party leader
2. Scene leader
3. Investigation team (2 men)
4. Hose team (4 men)
5. Emergency hull repair team (2 men)
6. Dewatering team (2 men)
7. Desmoking team (2 men)
8. Electrician
9. Messengers (2 men)
10. Phone talkers (2 men)
11. Stretcher bearers (2 men)
12. Fire extinguisher supply team (2 men)
13. Accessman

for a total of 24 men. Considering that a ship has several fire parties to cover the general quarters fire fighting requirements, the total number of required personnel can be quite substantial.

6.2 Equipment Considerations

Since the philosophy for fire fighting is based upon the availability of a large number of trained personnel, most of the fire fighting equipment used by the Navy is designed for manual operation. This includes:

1. detection and communication of the fact that a fire has occurred,
2. placing the fire water system in a condition of readiness,
3. supplying foam concentrate to the fire foam system, and
4. supplying all portable equipment to the scene of the fire.

The T3 tanker, i.e. the USNS Taluga, that is used as the reference ship for this study was formerly a U. S. Navy fleet oiler. It is equipped with the standard Navy fire fighting equipment. This equipment is probably adequate for its current mission, fleet at sea refueling, and crew size. The equipment is not adequate to satisfy the fire protection requirements when the tanker is operated as the storage tanker in the Offshore Bulk Fuel System. A primary reason for this inadequacy is the likely significant reduction in crew size that will accompany the change in the ship's mission.

6.3 Personnel Requirements

The personnel requirements will vary somewhat depending upon the range of operations that are required of the storage tanker. Since its normal mode of operation as an integral part of the bulk fuel storage system will be moored to the SPM and supplying fuel to the beach, we will first consider the personnel required for this situation.

In this case, normal watch standing will require a minimum of four (4) personnel per watch. The stations manned are the bridge, the pump room, the engine room, and the roving deck watch. Assuming a four section watch, sixteen (16) personnel are needed for watchstanding. Minimum maintenance of equipment aboard the ship will probably

require one (1) electrician, one (1) mechanical repairman, one (1) electronics technician, and one (1) hull technician.

Effective fighting of fires associated with operation of the storage tanker will probably require two fire fighting teams. Each team will need as a minimum one (1) team leader, two (2) hose teams of two (2) men each, two (2) men to haul portable equipment, one (1) electrician and one (1) corpsman for a total of eighteen (18) men.

Taking these requirements together means that the storage tanker can probably be operated with a crew of twenty (20) to thirty (30) men exclusive of the communications personnel.

If the tanker is required to get underway to conduct at sea refueluing, then other personnel will be required. Ship navigation will require a bridge watch of at least one (1) officer of the deck, one (1) helmsman, and one (1) quartermaster. Communication requirements will demand at least one (1) radioman and one (1) signal man. Assuming a three section watch requires thirty-six (36) watchstanding personnel. The necessary maintenance and service personnel requirements probably raise tne total crew requirements to fifty (50) for the underway operation of the ship.

6.4 Alternative Tanker Considerations

The Sealift Class Tankers have several features that make this class desirable for use as the storage tanker in the offshore bulk fuel system.

Ships of this class are designed for the transport of four cargoes. The built-in flexibility for cargo storage and transfer would make it most amenable for the storage and transfer of the three fuels that are planned for the offshore bulk fuel storage system. The installed cargo pumps are rated at 4200 gallons per minute,thus, have significantly more than the required capacity for the desired fuel transfer rates.

The Sealift Class tankers main source of power is provided by diesel engines. Since all major pumps and other components that are required for fuel transfer and fire safety are supplied by electrical energy, the engine room equipment that must be operated will be kept to a minimum. This feature will assist in minimizing the number of people that will be required for operation of the ship.

From the viewpoint of fire safety, the Sealift class tankers have a very effective fire fighting system. The fire main and fire fighting foam system coverage of the main deck area is quite comprehensive. The location of foam monitor nozzles, foam stations, and fire plugs make it possible to handle any reasonable fires that may result from fuel spills on the deck.

Foam concentrate for the Sealift class tankers' fire fighting foam system is currently supplied from a foam concentrate tank that is located at 1-74-2 just inside of the aft superstructure. This tank has a capacity of 475 gallons, and thus supplies enough foam solution for about 15 minutes of application. Foam is also supplied from this system to a sprinkler type system in the pump room.

At the present time ships of this class do not have an emergency shutdown system (ESD). We recommend the addition of an ESD that would stop the cargo pumps and close the pump discharge valves in response to a manually actuated signal. This system would assist in reducing the amount of fuel that will be spilled in the event that failures such as those previously described occur. Additionally, we recommend that pressure sensors be installed in the cargo pump discharge line to assist in the detection of fuel spills that might not normally be detected in a judicious manner. This could occur when the pump room is not continuously manned which is likely to be the case if operation with a minimum crew size is desired. This will also be a valuable aid in detecting the possibility of spills that occur on the SPM.

If the Sealift class tankers are used as the storage tanker for the offshore bulk fuel storage system storage tanker, then careful consideration needs to be given to the type of crew that mans the ship. Currently these ships are owned by private firms and are manned by civilian personnel. This situation is not necessarily a problem except for the fact that the ship will likely be operating in a combat zone. From the viewpoint of fire safety, each member of the crew should have specific assigned duties in the event that a fire alarm is sounded. Additionally, each crew member should be thoroughly trained in fire fighting methods and periodic fire drills should be conducted.

6.5 Procedures and Training

Current practice for U. S. Navy ships for fire fighting when in port is to have an organized in-port fire party. When a fire has been detected and the alarm sounded, the

in-port fire party mans the necessary equipment and fights the fire. Standard U. S. Navy equipment and fire fighting methods are used.

Since the storage tanker is moored to the SPM supplying fuel to the beach, its operation is somewhat similar to an in-port condition. This leads us to conclude that a fire fighting organization modeled after the in-port fire party concept should be utilized. Because of the likelihood that the number of onboard personnel will be reduced, we consider that all members of the ship's crew will be directly involved in the fire fighting organization. Therefore, we consider it to be of utmost importance that all of the ship's crew receive training in fire prevention, detection, reporting, and fire fighting. Completion of the U. S. Navy fire fighting school or its equivalent with refresher training every two years is recommended for all crew members. Further, if the ship is to be manned by U. S. Navy personnel, we recommend the assignment of personnel from the engineering rates with particular emphasis upon the hull technician (HT) rate.

The additional spill detection and isolation, inert gas system, and fire fighting equipment that is being recommended for installation on the ship should not require any <u>significant</u> additional training for the Navy personnel that will operate and maintain the equipment. Navy personnel of the appropriate rate for conducting operation, maintenance, and repair of mechanical, electrical, and electronics systems should have a more than adequate technical background. At most a one week school conducted by the equipment manufacturer should be sufficient to prepare Navy technicians to properly operate and maintain the additional equipment.

SECTION 7

HAZARD CONTROL RECOMMENDATIONS

The use of either of the reference tankers discussed in this report as the storage tanker in the Offshore Bulk Fuel System will result in a significant change in the operational environment for either tanker. In the case of the USNS Taluga, this means taking a ship designed for conducting at sea refueling operations and using it as a stationary fuel terminal. As previously discussed, this tanker currently has a civilian crew in excess of one hundred personnel. All shipboard systems are extremely manpower intensive.

If one of the Sealift class tankers is used then a point to point tanker will be converted into essentially a stationary fuel terminal. Again, all systems are manually operated; however, as previously discussed the existing fire fighting system is much more extensive than that on the Taluga. The Sealift class tankers are also manned by a civilian crew but with a greatly reduced number of personnel when compared with the Taluga, i.e., 25 as compared to approximately 125.

Because of the change in operational conditions for the ship selected, we believe that future operations will be conducted with a relatively small number of shipboard personnel. Crew size will probably be similar to that currently used on the Sealift class tanker. Because of these factors we are recommending additional equipment and procedures to assist with the control of fuel spills and fire hazards that may result from operation of the Offshore Bulk Fuel System storage tanker.

7.1 Spill Detection

Generally, the detection of fuel spills may be accomplished by manually patrolling and watching or by remote detection devices. The remote spill detectors can be classified according to their operating mode into direct and indirect detectors. Direct detectors are usually buoy-mounted and in direct contact with the marine environment. The fuel spill is detected due to a change of certain physical responses of the detector in the presence of fuel in the water. Surface characteristics of sea water would change if oil is spilled on water and could be detected by indirect detectors.

Optical scanning is the basic principle for indirect detection. Infrared or ultraviolet light sources can be used.

There are several types of commercial spill detectors available. The use of the indirect scanning detector is dependent on the mounting of a light source and a receiver. The configuration of the Offshore Bulk Fuel System is not such that the source and receiver can be mounted appropriately for use of this type of detector. The light interaction with the waves of the water can cause stray signals to indicate the presence of fuel when it is not there.

The direct buoy mounted detectors are very localized detectors. The only way complete and dependable detection can be accomplished with this type of detector is with large numbers of these strategically located. Several of these detectors require daily checks of alarm fuses to assure continued detector operation. We have been advised by manufacturers and those familiar with the use of these detectors that these devices will not survive in the sea state specified in the statement of work for this project.

Based upon our analysis of spill scenarios presented in Section 4 and the disadvantages with spill detector use in this application, we strongly recommend the use of a roving deck watch to assist with spill detection. The primary function of this watch is to detect those small leak rate component failures that can produce large spill volumes if they go undetected for appreciable periods of time.

In the case of the USNS Taluga, the roving deck watch is to conduct an inspection tour of the main deck from the aft superstructure to the bow of the ship. The total estimated time for this tour is fifteen (15) minutes with ten of these minutes to be spent in the area between the aft and amidship superstructure.

When visibility conditions permit, this roving watch will use field glasses to check the SPM for any unusual conditions.

In order to assist in ensuring that this deck watch is making his inspection tour in the prescribed manner, we recommend that a punch clock check-in system be used. Punch clocks should be installed at a position near the bow, near the hose connections to the fuel transfer manifold, and at the aft superstructure near the entrance to the pump room.

The roving deck watch will be responsible for punching his time card at each of these stations. His card will be turned over to his watch supervisor, probably the bridge watch, at the end of each watch. This watch will perform essentially the same functions if one of the Sealift class tankers is used.

Assistance in the detection of large leak rate events, such as a rupture of a fuel transfer hose, can be obtained by installing pressure sensors in the discharge lines of the cargo pumps. These sensors can be set to detect an abnormally low fuel transfer system pressure and to actuate an alarm to warn the pump room watch of the possibility of a large rate spill.

Spills in the cargo pump room can be detected by the pump room watch or by using combustible gas detectors. Combustible gas detectors are available in three main types: infrared analyzer, catalytic bead and solid state electrolytic cell. Infrared analyzer types use a pump to draw in atmospheric samples from the various locations to a central point where the infrared analyzer is located. These sample streams are sequentially injected into the infrared analyzer to determine the combustible gas concentrations at each sample point. This type of system is rarely used in hydrocarbon applications due to maintenance problems with the sampling system and its overall complexity.

Solid state electrolytic cell detector systems operate on the principle of allowing the combustible gas molecules to diffuse into a semiconductor; thereby, decreasing its electrical resistivity. The magnitude of the resultant current flow is related to the concentration of combustible gas molecules in the semiconductor which in turn depends on their concentration in the atmosphere. The current flow is sensed by the control/indicator module and is displayed on a meter in terms of percent LFL (lower flammable limit).

The catalytic bead system employs a heated ceramic bead coated with a catalyst as its sensor element. Combustible gas molecules are oxidized on the catalyst. The heat of combustion raises the temperature of the bead which increases the resistance of the platinum heater wire within the bead. This bead and an identical but uncoated bead (no catalyst) form two legs of a Wheatstone bridge circuit. The presence of a combustible gas alters the resistance of the coated bead only. The resultant imbalance in the bridge is monitored by the control/indicator module and is displayed on a meter in terms of percent LFL.

Gas sensors could be used in many locations on board a fuel tanker, but their greatest utility is for closed spaces where there is a danger of gas accumulation. In open areas, the practicality of gas sensors is reduced because the wind direction and speed may be so that the gas is blown away from the sensor or diluted too much for the sensor to detect.

Catalytic bead sensors are the type usually chosen for use in petroleum facilities. However, they do have some limitations. They will not work in inert atmospheres because they need oxygen to support combustion on the catalysts. They are inaccurate when the combustible gas concentration exceeds the lower flammable limit and can be very misleading if the gas/air mixture exceeds the stoichiometric ratio. They are subject to giving false alarms.

Solid state electrolytic cell types are reasonably accurate up to 200 percent LFL and they will work in inert atmospheres. However, because they are relatively new, there is little information available on their performance in petroleum installations.

We recommend that two catalytic bead type sensors be provided for each of the two cargo pump rooms to be located at the floor level. The control/indicating modules should be located on the bridge. There are at least two vendors which could supply this type of detection:

Mine Safety Appliance Company
600 Penn Center Boulevard
Pittsburgh, PA 15235

General Monitors, Inc.
3019 Enterprise St.
Costa Mesa, CA 92626

The estimated cost of this equipment is about $3500.

7.2 Fire Detection

Consideration was given to equipment which could be utilized in addition to the roving deck watch for deck fire detection. Fire detector types for possible use onboard tankers include ultraviolet sensors, smoke detectors, rate-of-temperature-rise sensors, and high temperature sensors, e.g., thermistors. Ultraviolet sensors detect the presence of larger than normal amounts of ultraviolet radiation when a flame is present. They are in common use in many petroleum facilities. These sensors have had trouble in the past

differentiating between fires, lightning, arc welding and sunlight reflection off the water. This limitation has been overcome by use of a more sophisticated electronic analyzer circuit. They are useful for both interior and exterior use.

Smoke detectors are available in two basic types. Light obscuration types incorporate a light source and photocells to sense the reduction in light intensity when smoke is present. Ionization types sense the change in ion flow within a chamber when products of combustion (basically molecular fragments) are present. Smoke detectors are generally limited to use in interior locations.

Rate-of-temperature-rise, high temperature and thermistor detectors are seldom used in petroleum facilities because their location with respect to the fire is too critical. Consideration was given to the use of a grid of high temperature detectors for deck fire detection, but the manufacturers of these detectors do not recommend their use outdoors. An air pressurized system could be utilized to detect a deck fire by air leakage when a fusible plug is melted. However, we believe that the roving deck watch is the most reliable way of achieving deck fire detection. Additionally, the roving deck watch will serve as an adequate method of detecting fires on the SPM.

7.3 Spill Isolation and Containment

The isolation and containment of spills is essential in order to limit the hazards of pollution and fire associated with tanker operations. Systems and procedures to rapidly suspend fuel transfer operations and to confine and clean up fuel spills will be discussed in this section.

7.3.1 Emergency Shutdown System

When a spill producing event occurs one of the best procedures is to stop the flow of fuel as quickly as possible. One method for accomplishing this termination of fuel flow is to install an emergency shutdown system (ESD).

The purpose of this emergency shutdown of the fuel transfer system is twofold:

1. to mitigate the hazards associated with the uncontrolled escape of the fuel
2. to minimize the loss of fuel

The ESD is designed to be used whenever a fuel spill and/or a fire is detected. Once a spill and/or fire is detected a decision will be made whether or not to activate the ESD. Once the ESD is activated from any one of the ESD stations a combination of manual and automatic operations must be performed. The ESD was designed for the Taluga; however, the design can be readily adapted to the Sealift class tankers with a minimum of alteration.

When the ESD is actuated an alarm should sound in the pump and engine rooms to shutdown the pumps. In the aft pump room the operator must coordinate with the engine room operator to disengage the pumps. In the midship pump room the operator must close the steam valves to the steam cylinders of the transfer pumps. The operator on the cargo deck must close the manual valves at the hose connection locations.

Four remote operated ball valves will block the flow of fuel through the vertical riser extending from the pump rooms to the cargo deck. The valves should be installed in the vertical risers in the pump rooms and as close to the pump discharge manifold as possible see Figures 2-2 and 2-3. A schematic diagram of the piping and block valves is shown in Figure 7-1. The closing cycle for the valves is started as soon as the ESD is activated.

Air was selected as the operating fluid for the valve actuator. The actuator was sized based on the availability of 100 psi air supply.(18) A schematic diagram of the valve and actuator is shown in Figure 7-2. As shown in the diagram, the valve actuator must receive electric power to open the air supply solenoid and to close the air bleed solenoid. The speed of opening and closing of the valve can be adjusted by the needle valve on the spring return side of the cylinder. Once electrical power is removed from the valve, the spring return closes the valve when the solenoids return to their normal states. The small hand valves permit air assisted, manual operation of the valves if the air supply is available. With the manual bleed valve open, the block valves can be opened with a handle.

The major design considerations for the block valves included:

1. fire safe
2. quick acting
3. fail safe
4. minimum flow restriction
5. manual override

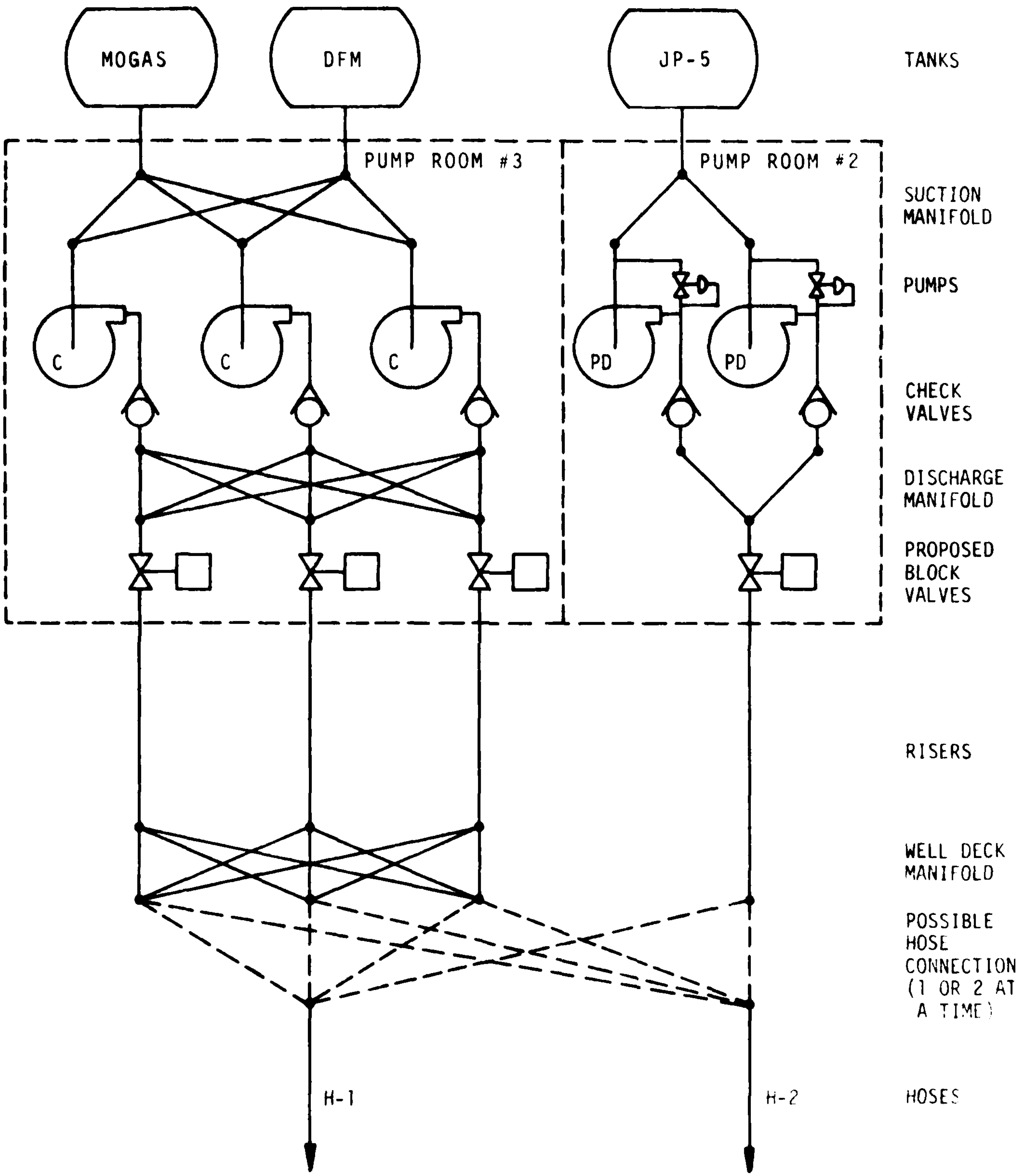
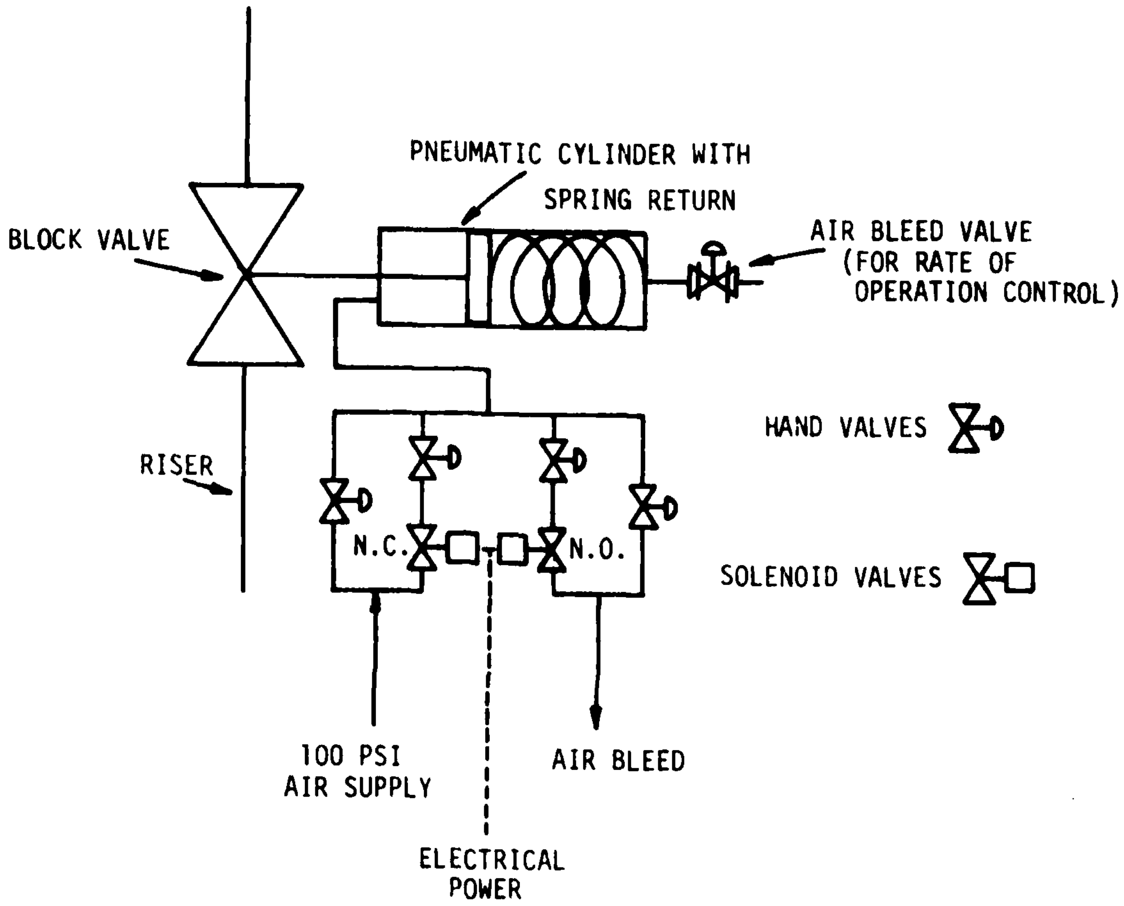


FIGURE 7-1. SCHEMATIC DIAGRAM FOR PIPING OF FUEL TRANSFER SYSTEM ON USNS TALUGA



NOTES: 1) AIR OPERATED VALVE
LOSS OF AIR → SPRING CLOSES
AIR PRESENT → VALVE OPEN

2) ELECTRICITY (SOLENOID)

3) MANUAL OPERATION (HANDLE)

FIGURE 7-2. SCHEMATIC OF REMOTE OPERATED VALVE WITH PNEUMATIC ACTUATOR

Ball valves were selected to meet the above criteria. Gate valves also meet the criteria, but, the actuators extend out perpendicular from the pipe flow direction whereas the ball valves actuator can be placed parallel to the risers.

Pressure surges (water hammer) occur in pipes carrying incompressible fluids when there is a sudden change in velocity of the flowing fluid. Sudden closing or opening of a valve will create the velocity change resulting in a series of pressure pulsations in the line. Since the block valve will be mounted in the vertical pipe riser, the distance from the block valve to the piping manifold is less than 50.0 ft and the pressure surge effect will be slight for an instantaneous valve closing. However, the valve and cylinder are bulky and the inertia will require time for valve closure. For spill estimates, a fifteen (15) second valve closing time should be used. For a 800 gpm flow rate considering a hose is connected to one riser, the spill after activation of the ESD would be:

$$\text{Spill volume} = (800\ \text{gpm})(.25\ \text{min})(.5)$$

$$= 100\ \text{gal}$$

where the factor (.5) is used to account for the reduction in flow as the valve closes.

The ball valve will create a pressure drop of approximately 0.1 psi across the valve at the design off-loading flow rate of 800 gpm. If 10-inch ball valves were installed in the 14-inch vertical riser pipe on the Sealift Atlantic, the pressure drop through the reducers and the valve would be 2.7 psi.

Quotes were obtained from vendors on 10-inch 150 lb ASA, flanged ball valves with carbon steel bodies, 316 stainless steel trim and an anti-static devise for JP-4/gasoline service. The valves have been fire tested to meet American Petroleum Institute (API) Standard 607 and Oil Companies Materials Association (OCMA) Specification No. FSV.1 Fire Safe Test. The quotes included the spring return (Fail Safe) pneumatic cylinder activators. The average values of the weights, cost and delivery schedules for the valves and actuators are:

Weight - 700 lbs/valve and actuator

Cost - $6,000/valve and actuator

Delivery - 10 to 12 weeks after receipt of order

Since the valves will be installed in the risers, the valve body will displace a section of pipe and the increased volume of the valve and actuator will be approximately 3 cubic feet. Recommended suppliers of the large ball valves in order of preference are:

1. Coastal Industries, Inc.
   Post Office Box 229
   Newton Square, PA 19073
   (215) 566-7070

   Valve - 10-inch #5233R Marwin-Firesafe Carbon Steel
   Actuator - Kinnetrol #180-Spring to close

2. AWC Texas Inc.
   Post Office Box 58266
   Houston, TX 77058
   (713) 488-2730

   Valve - 10-inch #DZ150F2200TT
   Jamesbury Firesafe Carbon Steel Ball Valve
   Actuator - Jamesbury 600ft-lb, spring return and hardware

3. H. D. Young
   Post Office Box 17636
   Dallas, TX 75217
   (214) 388-0580

   Valve - 10-inch Gate Valve, Flanged, 150 lb Series
   American Darling
   Actuator - American Darling Pneumatic Cylinder and hardware

The ESD shutdown stations are similar to manual fire alarm stations. The shutdown station has a recessed handle in order that accidental activation of the system is minimized. Once the alarm handle is pulled the ESD alarm is sounded on the bridge, the pump rooms and the engine room; a light is turned on at all the ESD stations and electric power is removed from the solenoids on the block valves. Power removal from the solenoids causes the block valves to close. ESD stations should be placed on the bridge, bow, engine room, pump rooms, main deck level (at access door of the pump room) and near the hose connection crossover piping. On the Sealift Atlantic the activation will also include opening the circuit that holds in the contactors of the electrical power for the main cargo transfer pumps.

Manual fire alarm stations such as Model numbers S464A and B , S465A and B, and a fire alarm control indicating

panel supplied by Honeywell can be used in the ESD alarm system. The uninstalled cost of the required components is estimated to be $5,000.

7.3.2 Fuel Spill Containment and Recovery

Containment is a way of immediately controlling the consequences of a fuel spill. The purpose of containment is generally to localize the spill, thus minimizing the extent of pollution and to concentrate the spill into a thicker layer so as to make removal easier. Applicable containment methods include commercial floating booms, sorbent booms and barriers, air or water streams, bubble barriers and chemical barriers. All of them are limited by environmental factors, such as wind, current and tide. Most of the time, booms are applicable in inner harbor or inland waterways. Unless the sea is calm, containment is usually ineffective and equipment will probably be destroyed.

Due to the high volatility, spills of gasoline and JP-4 are highly hazardous. Aging is required until the spill area has been declared to be non-hazardous by a safety officer using combustible gas detectors.(16)

Recovery of oil is usually accomplished by using skimmers or sorbents or by manual recovery. Each of these methods can be used to a certain extent as the cleanup operation progresses, and each has specific limitations depending on geographic location, quantity of the spill, the properties of the fuel and ambient climate conditions.

A skimmer is a mechanical device designed to remove oil from the water surface without causing major alterations in its physical or chemical properties. They can be classified according to their operation principles into five categories:

1. weir-type devices
2. suction devices
3. centrifugal devices
4. submersion devices, and
5. sorbent surface devices.

The effectiveness of any skimmer depends on a number of factors including the type of oil spilled, the thickness of the spill, the presence of debris, the location of the spill, ambient climate conditions and calmness of the sea. It requires a thorough knowledge of the advantages, limitations

and applicabilities of the available skimmer systems to select a suitable skimmer system.

Sorbents are any materials which will recover oil through either absorption or adsorption. There are three basic classes of sorbents:

1. natural organic materials such as hay, straw, peat moss and sawdust
2. mineral-based materials such as vermiculite, perlite and volcanic ash, and
3. synthetic polymeric sorbents, such as polystyrene, polyurethane, polyester foam and rubber.

Sorbents are manufactured in three forms: granular, mat and sorbent boom. The most effective sorbent is polymeric foam, plus it can be reused after the fuel is squeezed out. Generally, sorbents do not play the primary role in oil spill cleanup operations and are most commonly used for final cleanup of trace amounts of oil or to remove oil from areas which are inaccessible to skimmers.

Manual recovery of oil with buckets, shovels and similar equipment is frequently used for small spills which occur in ports and rivers or near populated areas. Available manpower and disposal facilities are the limiting factors in manual recovery.

An appropriate recovery approach may require the use of these methods individually or simultaneously, or in sequence. This may be different for each individual spill incident.

It is our belief that the method of spill containment and cleanup be appropriate to the use of the Offshore Bulk Fuel System. If the system is being used in an amphibious assault training operation, a completely equipped and well-trained Navy fuel spill containment and cleanup unit should be on standby for a short delay response to the tanker, if necessary. By utilizing this approach, the expertise of the specially trained personnel can be available while not burdening the tanker personnel with extra operational concerns.

If the Offshore Bulk Fuel System is part of an actual amphibious assault operation, we believe the approach should be different. The difficulty in using fuel containment booms in the open seas, the need to let spills of gasoline and JP-4 age before cleanup and the hostile enemy environment near this type of operation do not make spill containment and cleanup desirable. Instead it is important to disperse the

fuel spill as rapidly as possible to prevent ignition and further complications. To aid in spill dispersal and to minimize the potential for ship damage, a fire water monitor nozzle has been placed at the bow of the ship. This monitor should be an Akron Brass Company Style 506 with a 2" nozzle tip. A Style 4450 monitor fog straight stream nozzle also should be available for ship fire protection should the spill be ignited. This monitor and extra nozzle will cost about $2200 and will weigh about 150 lbs and occupy about 5 cu ft. In case of fuel spillage on water forward of midship, this nozzle and the two midship foam monitor nozzles (flowing water only) should be used in straight stream mode and directed into the spill. By this action and changing the nozzle spray direction, the spill will be agitated and evaporation will be enhanced. It will most likely be necessary to operate more water pumping capacity into the fire water system than the two 400 gpm pumps normally on line for this system.

7.4 Inert Gas System

Normal operation of the offshore bulk fuel system storage tanker will result in frequent unloading and loading of the cargo tanks. During these operations explosive mixtures may exist in the vapor space of the cargo tanks. In order to minimize the possibility for fires and explosions in the cargo tanks some method for preventing the formation of the flammable mixture is normally used.

7.4.1 Requirement for Explosion Prevention

An explosion may be viewed as a rapid equalization of a high pressure gas with the surrounding environment. The equalization must be sufficiently fast so that the energy contained in the high pressure gas is dissipated in a shock wave. The source of the high pressure gas is typically a rapid chemical reaction which requires three principal ingredients:

1. Fuel
2. Oxygen
3. Ignition Source

If these three ingredients are available, then a fire or explosion may result. Depending upon the circumstances of the mixing of these ingredients, an explosion followed by a fire or a pool fire may be the result.

In the case of the cargo tanks of the storage tanker, or with any petroleum products carrier, the fuel that can become involved in an explosive chemical reaction is the light hydrocarbon vapors in the gaseous space above the liquid. Hence, the fuel for an explosion or fire is limited by the amount of hydrocarbons in the vapor phase.

In order to minimize the risk of fires and explosions associated with tanker operations, some method(s) must be employed to effectively remove at least one of the three principal ingredients that are required for the reactions to take place.

Since the purpose of the tanker is to store and transfer hydrocarbon fuels, the removal of the fuel vapors is extremely difficult. Some tanker operations can be conducted so that the vapor composition is controlled by having excess hydrocarbons for a flammable mixture to occur. This is often referred to as the <u>too rich</u> condition. Since the function of this tanker is to supply fuel to the forces ashore, minimizing fire and explosion hazards by maintaining the cargo tanks in the <u>too rich</u> condition is not feasible.

The potential sources of ignition within a cargo tank are lightening strikes, collision, malfunctioning flame arrestors, hostile action, or electrostatic discharges created by sloshing fuel droplets. Since these ignition sources are essentially impossible to remove, minimization of fire and explosion hazards by control of ignition sources is not feasible.

The most widely used method for reducing the risk of cargo tank fires and explosions is to remove the oxygen supply to the tank vapor space. The source of oxygen is the flow of atmospheric air into the tank when the tank is being unloaded. This air is introduced to replace the volume originally occupied by the offloaded liquid cargo in order to maintain specific limits on the pressure within the cargo tanks.

The oxygen supply to the vapor space of the cargo tanks is limited by replacing the volumetric displacement air by an inert gas that is low in oxygen content (i.e. less than 5% by volume.). In this way the hydrocarbon-oxygen concentratons that are found in the vapor phase of the cargo tanks are kept below the flammable mixture zone.

7.4.2 Methods for Supplying Inert Gas

Inert gas can be generated for this purpose by three separate systems. These systems are:

1. Flue gas from the propulsion boiler system
2. Independent flue gas generation system
3. Nitrogen generation unit

Of the three systems listed above the propulsion boiler flue gas generation system is the least expensive system to install. The independent flue gas generation system is slightly more expensive, and the nitrogen generation system is the most expensive unit to have installed aboard the vessel. However, from a total life cycle cost standpoint, it appears that the independent gas generation and nitrogen generation units may be the most cost effective due to the extensive maintenance requirements of the system that utilizes boiler generated flue gas.

It is important in obtaining an inert gas to maintain oxygen level and also to reduce the amount of sulfur oxide compounds in the flue gas. The oxygen level control is required from the basic desirabilities of obtaining a reasonable flue gas with proper inerting characteristics. Sulfur dioxides are undesirable from a corrosion, instrument reliability and product absorption characteristic. Increasing the amount of sulfur in the liquid cargo is certainly undesirable, no matter what liquid product is being carried from crude oil to refined products. Due to combustion air variations in the propulsion boiler system, control of the oxygen level and sulfur dioxide levels can be somewhat difficult.

The control of the burner in the independent flue gas generation system is somewhat simpler than the propulsion boiler generated flue gas. Furthermore, the independent flue gas system can utilize a sulfur free or low sulfur feed stock, thereby reducing the sulfur dioxide in the generated flue gas.

The nitrogen system, which is obtained through the use of a pressure swing adsorption unit, is virtually free of sulfur compounds and the acidic nature of CO_2 which is a substantial constituent in flue gas. Therefore the characteristics of the nitrogen generated inert gas are the most desirable from an operational and product specification viewpoint.

Inert gas plants utilizing scrubbed flue gases from the ships boilers consist of several inerting operations. The

unit to cool and remove soot and particles. The cooled flue gas is then transferred to the cargo tanks through a network of piping by a central blower. Typically, the central blower will be rated at a minimum of 125% of the total discharge capacity of the cargo pumps. Since the inert gas must displace the amount of liquid being offloaded by the cargo pumps, the blower is rated in excess of the cargo volumetric displacement rate in order to maintain the capability of pressure control.

The inert gas from the boiler flue gases is required to have an oxygen content less than 5%, with high level alarms set at 7 to 8% oxygen. This oxygen control provides a margin of safety since any hydrocarbon gas mixture with an oxygen content of less than 10% is inert. Typical inert gas constituents are CO_2 (12-15%), oxygen (2-4%), SO_2 (.01 - .03%), nitrogen (75-80%), and water vapor (4-7%). The quality of the inert gas is dependent on the load on the ship boilers and the capabilities of the scrubbing system.

Separate auxiliary burners independent from the ship propulsion system provide similar flue gas composition. However as noted previously, a low sulfur feed may be utilized to reduce the SO_2 level, thereby precluding the absorption of the sulfur dioxide by the liquid cargo.

For the nitrogen generation units, the inert gas product is essentially free from moisture and carbon oxides. Small quantities of argon present in feed air are also in the nitrogen inerted gas. The purity of the nitrogen generated inert gas is typically 99%, with the remaining 1% mainly oxygen with a small amount of argon. Since the pressure swing adsorption unit requires pressurization of feed air supply, the nitrogen inert gas is typically delivered at about 100 psig delivery pressure.

Various piping arrangements are utilized throughout the shipping industry to provide either a dilution or a displacement gas inerting technique. In the dilution method, the incoming inert gas mixes with and thereby dilutes the existing tank gas until the required low concentration is reached. In the displacement method, incoming gas physically displaces the existing tank gas without mixing. Either method has the potential of obtaining a properly inerted tank vapor space.

7.4.3 Reliability of Inert Gas Systems

A study of maintenance problems associated with inert gas blanketing systems that have been used for the past six years aboard crude oil and product carriers was conducted by Det Norske Veritas. Out of 53 ships surveyed, 75% experienced damage to the inert gas central blower, rendering the inert gas system inoperable for varying lengths of time. All of these systems were based upon generation of inert gas system from the boiler flue gas. The amount of time that the inert gas system was unavailable for operation was not determined. Hence, although maintenance problems are definitely cited, the total reliability and availability of inert gas blanketing systems is uncertain. Because of the publication of the experience with inert gas central blowers, most retrofitted and new systems are utilizing more advanced materials (such as inconel) to overcome the observed problems with the older inert gas blowers.

The operating experience over a period of years points up the need for great care in the design of inert gas systems, materials utilized in system components, and maintenance of the inert gas equipment. In addition to the reported problems with the central blower, scrubbers, float lines, uptake valves and expansion joints also contributed to operating difficulties. Most common problems are corrosion and particulate buildup in the various componets.

The main components of a flue gas inerting system are:

1. Boiler exhaust uptake valves
2. Boiler exhaust piping
3. Water scrubbing unit
4. Demisting unit
5. Cool flue gas transfer piping and control valves
6. Parallel fan units
7. Check valves for water seals
8. Cargo tank network of piping and nozzles
9. Pressure/vaccum relief
10. Cargo control panel

A detailed reliability study of cargo inert gas blanketing systems has not been undertaken. Due to the changing technology, particularly in the area of materials utilized in the blower units, it appears that reliability of these units may be increasing.

The nitrogen generation units, which utilize pressure swing adsorption, consist of an air compressor and paralled molecular sieve units. Similar operating systems have been

utilized for many years in various nitrogen and gas handling service. A high reliablity for this unit is expected, however, no data or experience has been reported for these units in shipboard application.

The U. S. Coast Guard, in the recently published inert gas regulations (Federal Register Vol. 44 No. 224 Monday, November 19, 1979) stated that they feel that substantial progress has been achieved in the technlogy of inert gas systems. They base their conclusions on their awareness of advances in ICS technology, which was spurred by the publication of the Det Norske Veritas study.

The International Chamber of Shipping and the Oil Companies International Marine Forum have collaborated on a recent publication entitled "Inert Flue Gas Safety Guide." This guide is receiving wide distribution within the shipping industry and being considered by the IMCO subcommittee on fire protection as a supplement to the requirements for inert gas systems contained in SOLAS 74/78. Furthermore, the U. S. Coast Guard has developed an inspection guide for inert gas systems to be used by marine inspectors. This guide is included as a chapter in the Marine Safety Manual.

7.4.4 Recommendations

Because of the almost continuous offloading and loading operations that are to be conducted by the storage tanker, we recommend that the tanker be fitted with a cargo tank inerting system. Additionally, because of the fuel quality requirements, we recommend that a nitrogen gas generation system or a closely controlled independent flue gas generation system be used.

Of the ships considered in this study, the USNS Taluga does not have a tank inerting system of any kind. If the Taluga or any tanker that does not have a inert gas system is to be used for the storage tanker, we recommend installation of a nitrogen inert gas system. Potential suppliers of this system are:

1. AIRCO CORPORATION
   Murray Hill, NJ

2. SMIT NYMEGEN CORP.
   1511 K St., N.W.
   Washington, D.C. 20005

Units of the size required to support the desired fuel discharge rate will cost approximately $400,000 installed. These units will supply approximately 300 cfm of inert gas. They weight approximately 6600 pounds and require approximately 325 cubic feet of space. These weight and volume figures do not include the piping systems.

The Sealift class tankers do have inert gas systems that are supplied by the propulsion system flue gases. Because of the fuel purity requirements and of the possible contamination problems of this system, that have been discussed previously, we again recommend use of the nitrogen pressure swing adsorption system. The present system may be useable but will probably require upgrading of some system components. Additionally, a careful check will need to be kept on the gas supplied by the system in order to avoid unacceptable fuel contamination.

7.5 Deck Foam Systems

The USCG regulations require that a deck foam system be installed on all tank vessels as discussed in Section 2.4. In order to meet these regulations, all components of the deck foam system must be approved by the U. S. Coast Guard and be listed in their "Equipment List" CG-190.

In Section 2.4.1, it was noted that the Navy uses AFFF foam for foam fire protection on its ships. It was also noted that no commercially available AFFF concentrate has passed the Coast Guard fire performance test. Because of the Navy's choice of AFFF foam as its primary foam agent, AFFF concentrate will be readily available through normal Navy supply channels. Other foam concentrates chosen for use for the tanker foam system in the Offshore Bulk Fuel System would not be normally available. Also, if the proposed deck foam system is designed for a concentrate other than AFFF, the normally available AFFF concentrate could be introduced into the system and improper foam system operation result. For these reasons, we believe that the best choice of a foam concentrate for the deck foam system for the fuel storage and transfer tanker would be AFFF.

The foam system provided for the USNS Sealift Atlantic is capable of providing an adequate supply of foam to handle the potential deck spills and fire problems associated with the Offshore Bulk Fuel System operation. However, because the foam system also supplies the smothering system in the pump rooms, we recommend that the foam concentrate storage

capacity be increased. This capacity can be doubled relatively easily by adding another concentrate tank.

A deck foam system for the cargo deck area of the USNS Taluga has been designed in order to improve the protection level to that necessary for the Offshore Bulk Fuel System Operation. The system has been outlined so that with only minor design variations a choice between AFFF and the USCG approved regular protein foam could be made prior to detail specification of the foam system equipment.

The cargo transfer area (between the machinery area and the midship bridge house) on the Taluga is below a wooden work deck. The wooden deck height above the cargo deck is such that a normally used system of monitors for foam distribution would not be effective for proper foam distribution. As a result, we have designed a group of three fixed pipe foam sprinkler systems to protect this area. Each of these three systems protects approximately one-third of the cargo transfer area.

A system of foam monitors and hose lines has been designed to protect the area above the cargo tanks forward of the midship bridge house. Two monitors are proposed at the forward starboard and port sides of the bridge house on the 01 level. Also, one monitor is located at the after edge of the forecastle deck slightly starboard of the ships centerline on the 01 level. This system is designed for one of the bridge house nozzles to be used in combination with the forecastle nozzle to protect the half of the deck area corresponding to the midship monitor being used. Each monitor nozzle has a hose line connection nearby with 100 ft of 1 1/2-inch hose and a foam nozzle provided.

The fixed pipe foam sprinkler system is shown in Drawing EA-485-7-1. The pipe sizes for all the branch lines are consistent except where differences are indicated. Each of the three systems is supplied with foam solution through a dedicated, valved supply line. The valve in each system supply is to be a remotely operated, pneumatically powered gate valve for quick system operation from the bridge.

The nozzle proposed for use in the fixed pipe foam systems is the SD-2 1/2PA foam water sprinkler made by Automatic Sprinkler Corp. of America. System hydraulic calculations were performed for the pipe sizes and schematic configuration shown in Drawing EA-485-7-1 and produced the following foam solution flow requirements at approximately 63 psi at the foam proportioning skid discharge:

Area I	857 gpm
Area II	707 gpm
Area III	730 gpm

It should be remembered that these calculations can only be approximate until specific piping configurations allowing for obstructions can be formulated for a specific ship. Matching of the largest demand fixed pipe system (Area I) with the fire water supply normally available, shows that this system will operate at 920 gpm at 71 psi at the discharge of the foam proportioning skid. The fire water system normally available is two 400 gpm, 125 psi fire pumps.

Similar hydraulic calculations have been performed for the monitor system shown in Drawing EA-485-7-2. The calculations assume one midship and the forward foam monitor are operating simultaneously. The foam solution flow requirements of this system from the hydraulic calculations are about 755 gpm at 73 psi. Matching of the monitor system with the fire water supply normally available, shows that the monitor system will operate at 825 gpm at 86 psi at the discharge of the foam proportioning skid.

When a wide range of foam solution flow rates and pressures are necessary for a given foam system, as is the case here, a balanced pressure system is the best choice for the proportioning system. The foam system equipment used in this proposed design is that of the National Foam System, Inc. The proportioning system chosen was the PSP-220. This is a skid-mounted proportioning unit ready to be connected to the foam concentrate tank and fire water supply. The ratio-flow proportioner used in this assembly is U. S. Coast Guard approved. However, the skid-mounted assembly itself is not yet Coast Guard approved. The National Foam Co. has advised that this approval will be sought in the near future. National Foam Co. states that the PSP-220 proportioner can be used either for 6% AFFF or 3% regular protein foam with the proper proportioning orifice installed in the ratio-flow proportioner. National also advises that a proportioning system for AFFF concentrate should have all brass components which will be in contact with concentrate changed to iron or steel because of brass-AFFF concentrate interaction.

The USCG regulations specify that a quantity of foam concentrate must be provided for 20 minutes of operation of the system with the highest flow rate. The highest flow rate for the foam system is 920 gpm. This flow rate requires that

a 1200 gallon concentrate storage tank be provided if 6% AFFF concentrate is utilized, and, a 600 gallon tank, if 3% regular concentrate. We recommend that an adequate spare supply of foam concentrate be available to completely refill the storage tank. If the lowest expected ambient temperature where the tanker will be operated is below about 20°F (-6.6°C) for 3% regular foam or 35°F (1.7°C) for military specification MIL-F-24385 AFFF, special provisions must be made to keep the foam concentrate temperature above its allowable minimum temperature. This can be accomplished by providing heating pads at the storage tank bottom and insulating the tank to reduce heat leakage.

For the final extinguishment of fires in the cargo transfer area, hose lines may be needed. If AFFF concentrate is chosen for the system, this can be accomplished by providing an additional 100 ft of 1 1/2-inch fire hose for each of the two existing AFFF foam systems in the cargo transfer area. This will provide for two foam hose streams to any part of the cargo transfer area. If regular protein foam concentrate is chosen, provisions for foam nose stream capability will have to be provided from the fixed pipe system for fire mop up operations.

The monitor system forward of the midship bridge consists of three PC-50 foam monitors. Supplied by the same piping system are three hose line assemblies (See Drawing EA-485-7-2), one located near each monitor. These hose line assemblies consist of 100 ft of 1 1/2-inch hose and a foam nozzle appropriate for the concentrate to be used in the system. National Foam's PC-12 nozzle is appropriate for either AFFF or regular protein foam concentrate. This nozzle is Coast Guard approved for regular protein foam. For AFFF concentrate, a nozzle meeting military specification MIL-N-24408 could be used. The Akron Brass Company's nozzle Style 3018 is an example of a nozzle conforming to the previously mentioned mil spec.

The cost of the uninstalled hardware for the deck foam system will depend on whether AFFF or regular protein foam concentrate is used in the system. The estimated equipment costs are about $37,000 if AFFF concentrate is used and about $34,000 if regular protein concentrate is used.

Table 7.1 presents weights and container volumes of foam equipment to help with transportation and storage planning. The total necessary weight and storage volume for the foam system by concentrate type is presented below:

TABLE 7.1

WEIGHTS AND CONTAINER VOLUMES OF FOAM SYSTEM EQUIPMENT

	Weight Per Unit(lb)	Volume Per Unit(cu ft)	Weight Total(lbs)	Volume Total(cu ft)
From National Foam System, Inc.				
PSP-220 Proportioning Skid(1)	1,400.0	83.0	1,400.0	83.0
Foam Concentrate Tank				
1200 gal (AFFF) (2)	2,030.0	314.0	2,030.0	314.0
600 gal (regular) (1)	885.0	159.0	885.0	159.0
Foam Water Sprinklers (130)(est)	10.0	0.1	130.0	13.0
PC-50 foam monitors (3)	22.5	3.0	67.5	9.0
PC-12 Portable foam nozzle (3)	15.0	2.0	45.0	6.0
Heating Equipment (if needed)	10.0	10.0	10.0	10.0
Alternate Portable Nozzle from Akron Brass Co. Portable Foam Nozzles				
Style 3018 (AFFF only)(3)	9.5	0.5	28.5	1.5
Pipe and Fittings (estimate)	13,000.0	200.0	13,000.0	200.0
Foam Concentrate(55 gal container)				
6% AFFF (22)	533.0	12.8	11,726.0	281.6
3% Regular Protein (11)	571.0	10.7	6,281.0	117.7

TABLE 7.1

(Continued)

WEIGHTS AND CONTAINER VOLUMES OF FOAM SYSTEM EQUIPMENT

	Weight Per Unit(lb)	Volume Per Unit(cu ft)	Weight Total(lbs)	Volume Total(cu ft)
DeZurik Resilent Seat Wafer Type 6" Butterfly valve, Figure 632 (6)	28.0	2.0	168.0	12.0
DeZurik Pnuematic Operator KWGC 6 (4)	37.0	2.0	148.0	8.0
DeZurik 4-way solenoid valve-explosion proof (4)	5.0	.5	20.0	2.0
Swing Check Valve, butt weld (2)	165.0	0.75	330.0	1.5

Concentrate	Weight(lbs)	Volume(cu ft)
6% AFFF	29,075	941
3% Regular Protein	22,485	622

We have been advised by National Foam that the foam system equipment could be delivered in 12 to 16 weeks from the time of ordering.

SECTION 8

RELIABILITY, MAINTAINABILITY, AVAILABILITY AND INTEGRATED LOGISTICS SUPPORT

The reliability and availability of the major systems are analyzed in sections 8.1 through 8.6. Distinguishing characteristics of the system design, operation and maintenance are discussed for each system. Section 8.7 is a matrix of the reliability and availability for the major systems. Section 8.8 discusses the additional preventive maintenance and logistic support requirements created by the proposed new systems and operating scenario. Section 8.9 discusses the additional corrective maintenance and logistic support requirements imposed by the greatly increased operating times and the proposed new systems. Section 8.10 discusses the development of the data base used in all reliability, availability and fault tree calculations.

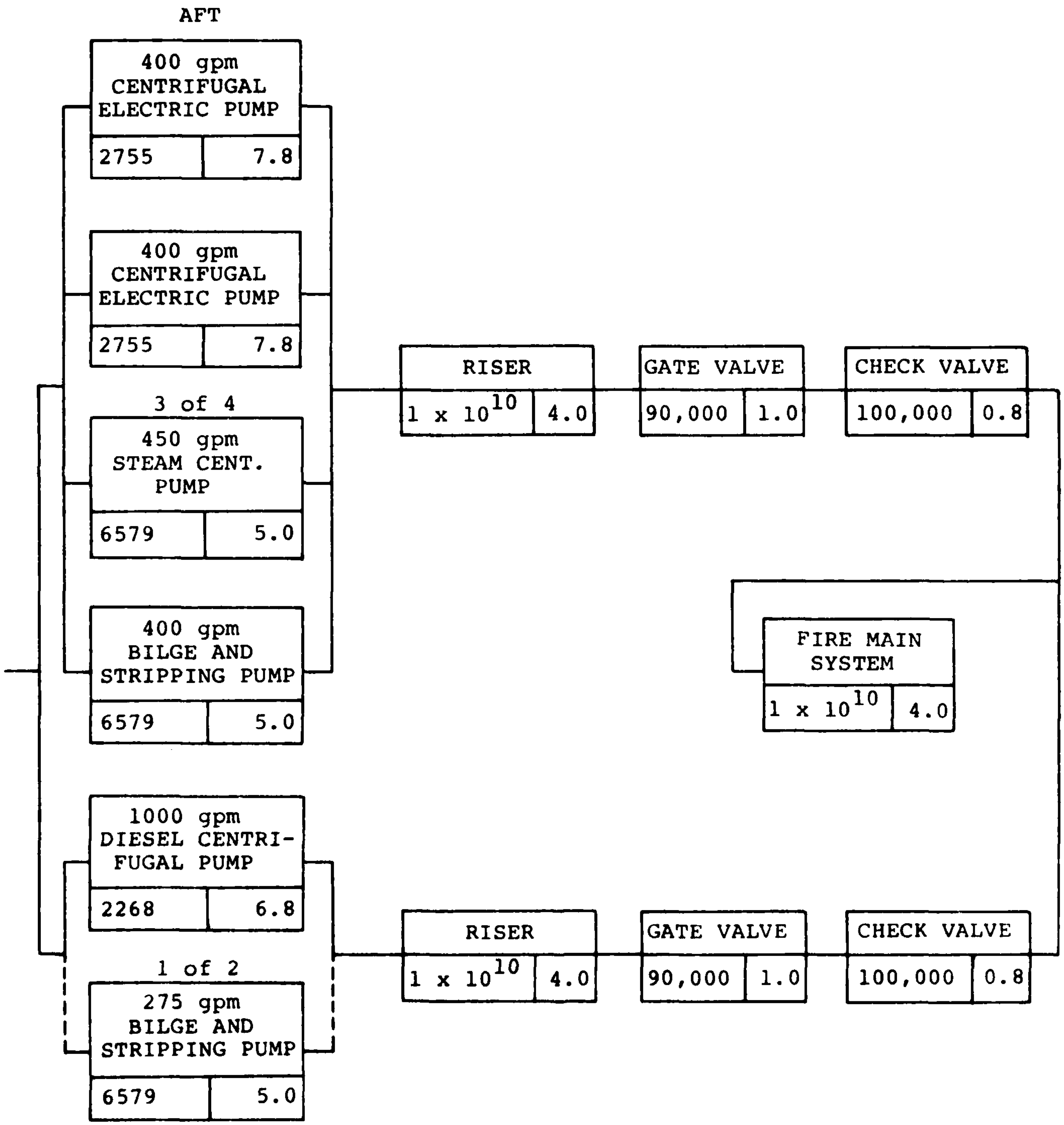
8.1 Fire Water System

The fire water system is essentially failure free due to the high level of redundancy which exists among the many combinations of pumps and the high mean time between failure (MTBF) and low mean time to repair (MTTR) belonging to components such as pipes and valves which have the least redundancy. Figure 8-1 is a reliability/availability block diagram. By inspection of Figure 8.1, it is apparent that the reliability and availability of the fire water system exceeds 0.85 (eighty-five percent).

It is more meaningful to examine the fault trees for the fire water system and look at two sets of failures - total loss of fire water and fire water delivery volume below 1000 gpm (the minimum believed necessary to fight a tanker fire). Fault tree 5-10 shows that the probability of fire water loss due to essentially instantaneous random mechanical failures is 5.8×10^{-11}. This means that it will essentially never occur. Fault tree 5-11 examines the more realistic case of fire main capacity reduced below 1000 gpm and examines external forces such as collision at sea and battle damage which involves less than a direct and fatal hit on the cargo. The probability of reducing fire water capacity below 1000 gpm is found to be 4.1×10^{-10}. It must be remembered that a direct hit with a several hundred pound

FIGURE 8-1

FIRE WATER SYSTEM RELIABILITY/AVAILABILITY BLOCK DIAGRAM



warhead on the fuel tanks will probably result in the loss of the ship.

8.2 Liquid Cargo Systems

The contract requires that the system be able to deliver 800 gpm of JP-5, diesel or MOGAS through each of two pipelines with an availability and reliability of 0.85. Either of the steam driven positive displacement pumps in pump room #2 of the Taluga is capable of delivering 800 gpm of JP-5 under most conditions. There is also a stripping pump available which could be used if necessary.

In pump room #3 of the Taluga, there are three steam driven centrifugal pumps. Any one of these pumps can deliver 800 gpm of MOGAS or diesel. There is also a positive displacement stripping pump which can be placed on line if necessary.

Examination of the piping diagrams for the purpose of developing a reliability/availability block diagram reveals there are so many success paths involving pipes, valves and risers that the probability of system failure due to these components is less than 10^{-10}. Accordingly, these components are treated as having a reliability of 1.0.

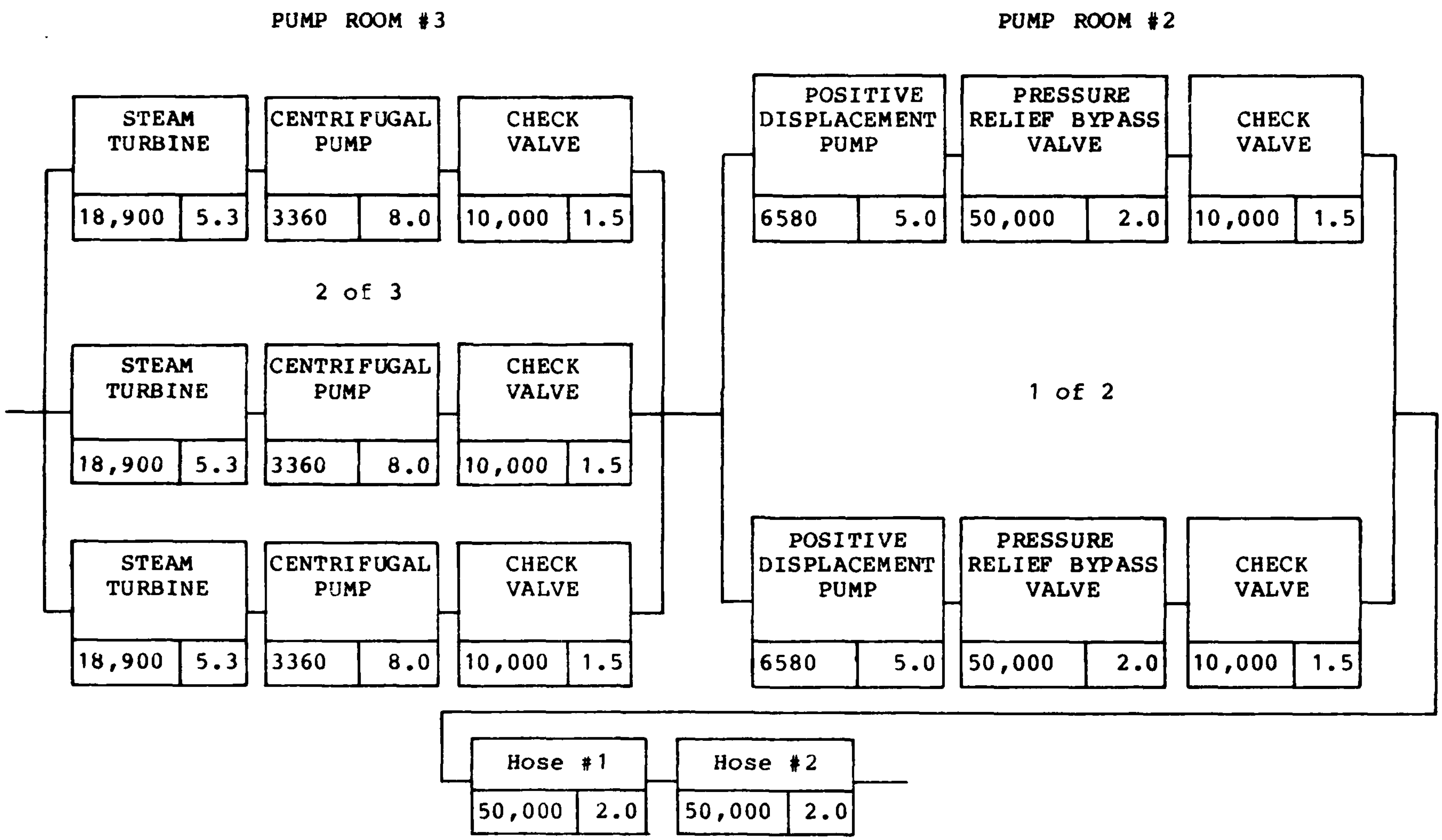
Figure 8-2 is a simplified reliability/availability block diagram of the liquid cargo systems. To be conservative, the possible use of the stripping pumps is disregarded in both pump rooms. The model requires that two of three centrifugal pump assemblies are required in pump room #3 and one of two positive displacement pump assemblies are required in pump room #2. Both cargo transfer hoses to the SPM are required for system success. The steady state availability can be computed as follows:

$$\text{Availability} = \frac{\text{Mean time between failure}}{\text{Mean time between failure+mean time to repair}}$$

$$A = \frac{\text{MTBF}}{\text{MTBF + MTTR}}$$

FIGURE 8-2

LIQUID CARGO SYSTEM RELIABILITY/AVAILABILITY BLOCK DIAGRAM



Pump Room #3

$$A_1 = A_{\text{Steam Turbine}} = \frac{18,900}{18,900 + 5.3} = .999720$$

$$A_1 = A_{\text{CNTRFGL Pump}} = \frac{3660}{3360 + 8.0} = .997625$$

$$A_3 = A_{\text{Check Valve}} = \frac{10,000}{10,000 + 1.5} = .999850$$

$$A_X = A_{\text{C P ASSY}} = A_1 \cdot A_2 \cdot A_3 = .997195$$

$$A_{PR\#3} = A_X^3 + 3A_X^2(1 - A_X)$$

$$= (.997195)^3 + 3(.997195)^2(.002805)$$

$$= .991609 + .008368$$

$$= .999977$$

PUMP ROOM 2

$$A_4 = A_{\text{POS DISPL PUMP}} = \frac{6580}{6580 + 5.0} = .999241$$

$$A_5 = A_{\text{PRB VALVE}} = \frac{50,000}{50,000 + 2.0} = .999960$$

$$A_6 = A_{\text{CHECK VALVE}} = \frac{10,000}{10,000 + 1.5} = .999850$$

$$A_Y = A_{PDP\ ASSY} = A_4 \cdot A_5 \cdot A_6 = .999051$$

$$A_{PR\ \#2} = A_Y^2 + 2A_Y(1 - A_Y)$$

$$= (.999051)^2 + 2(.999051)(.000949)$$

$$= .998103 + .001896 \approx .999999$$

HOSE ASSEMBLIES

$$A_7 = A_{HOSE\ \#1} = \frac{50,000}{50,000 + 2} = .999960$$

$$A_8 = A_{HOSE\ \#2} = A_{HOSE\ \#1} = .999960$$

$$A_{HOSE\ ASSY} = (A_7)(A_8) = (.999960)^2 = .999920$$

$$A_{LIQ\ CARGO\ SYSTEM} = A_{PR\ \#3} \cdot A_{PR\ \#2} \cdot A_{HOSE\ ASSY}$$

$$= (.999977)(.999999)(.99992)$$
$$= .999896$$

The availability of the liquid cargo system exceeds the required availability by several orders of magnitude. Determining the reliability of repairable redundant systems is more complicated. By inspection of the block diagram, a reasonable approximation can be arrived at by the following steps:

1. Compute the failure rate of each pump assembly
2. Let the operating time of the redundant assemblies equal the assembly MTTR
3. Determine the reliability of the redundant assemblies and their complement for time equal to MTTR
4. Recall that the meaning of availability is the probability that a particular assembly is operable at any given time
5. If we use the unavailability of a pump assembly, then we are using the probability that it is down
6. For a system failure to occur, redundant assemblies must fail within the assembly MTTR.

PUMP ROOM #3

	λ	MTTR	λ MTTR
STEAM TURBINE	.000053	5.3	.000281
CNTRFGL PUMP	.000298	8.0	.002389
CHECK VALVE	.000100	1.5	.000150
	.000451		.002815

$$R_x = e^{-\lambda t} = e^{-.002815} = .997189$$

$$Q_x = 1 - R_x = .002811$$

$$(1 - A_x) = (1 - .997195) = .002805$$

$$Q_{PR\ \#3} = (1 - A_x)[Q_x^2 + 2Q_xR_x]$$

$$\begin{aligned}
&= (.002805)[(.002811)^2 + 2(.002811)(.997189)] \\
&= (.002805)[.000008 + .005606] \\
&= (.002805)(.005614) \\
&= .000016
\end{aligned}$$

$$R_{PR\ \#3} = 1 - Q_{PR\ \#3}$$

$$= 1 - .000016$$
$$= .999984$$

PUMP ROOM #2

	λ	MTTR	λ MTTR
POS DISPL PUMP	.000152	5.0	.000760
PRB VALVE	.000020	2.0	.000040
CHECK VALVE	.000100	1.5	.000150
	.000272		.000950

$$R_Y = e^{-\lambda t} = e^{-.000950} = .999040$$

$$Q_Y = 1 - R_Y = .000960$$

$$(1 - A_Y) = (1 - .999051) = .000949$$

$$Q_{PR\ \#2} = (1 - A_Y)(Q_Y)$$

$$= (.000949)(.000960)$$
$$= .000001$$

$$R_{PR\ \#2} = 1 - Q_{PR\ \#2} = 1 - .000001 = .999999$$

It is apparent that the reliability of the pumping systems exceeds the reliability requirement by several orders of magnitude.

The hose assemblies are the weak links of the system. The MTBF used in calculations is a reasonably high 50,000

hours. This should be interpreted as the reliability of the hose assembly if and only if the inspection and test procedures discussed in Section 2.4.4 are followed. The hose assemblies must be replaced before end of life expectancy.

For a one year scenario, the reliability of the hose assemblies will be as follows:

$$\lambda HOSE = \frac{1}{MTBF_{HOSE}} = \frac{1}{50{,}000} = .000020$$

$$R_{1\ HOSE} = e^{-\lambda t} = e^{-(.00002)(8766)} = e^{-.17532}$$

$$R_{1\ HOSE} = .8392$$

$$R_{2\ HOSES} = (.8392)^{2} = .7043$$

Therefore, the reliability of the liquid cargo systems cannot be achieved and there isn't much that can be done about it. There is a great deal of uncertainty in regard to hose reliability due to poor record keeping on the part of the manufacturers and users. It is not known at this time whether the regular inspection and test discussed in Section 2.4.4 really improves the MTBF beyond 50,000 hours or whether it is required to justify an MTBF as high as 50,000 hours.

The positive aspect is that failure only means half the delivery capacity is lost until the system is restored. The MTTR is estimated to be as high as 4.0 hours for hose sections completely in the water. Much shorter times can be expected for failures occurring at the SPM or ship.

Due to the high rates of utilization, all of the preventive and corrective maintenance procedures and spares provisioning associated with the liquid cargo systems will be greatly accelerated. These points are discussed in detail in subsequent sections of this report.

8.3 Recommended Fuel Transfer Area Foam System

The reliability/availability block diagram of the fuel transfer area foam system is shown in Figure 8-3. There are several distinct features in this system that deserve comment. The first is the redundant control system for actuating foam production and distribution. The preferred mode is fully automatic operation initiated by a pull box on the bridge. If any or all portions of the automatic system fail, then manual operation is possible.

The second feature is that the system is demand rather than operating time oriented. The reliability is irrelevant because of the short duty cycle of the system. Therefore, the dominant consideration is the intrinsic steady state availability.

The availability is determined by six assemblies - the sector selection gate valve; operating gate valves #1 and #17; the 15 HP electric motor and controller; the 85 gpm positive displacement concentrate pump; and the selected group of area nozzles. The availability can be computed as follows:

Gate Valve: $A_{GV} = \frac{25,000}{25,000 + 0.5} = .99998$

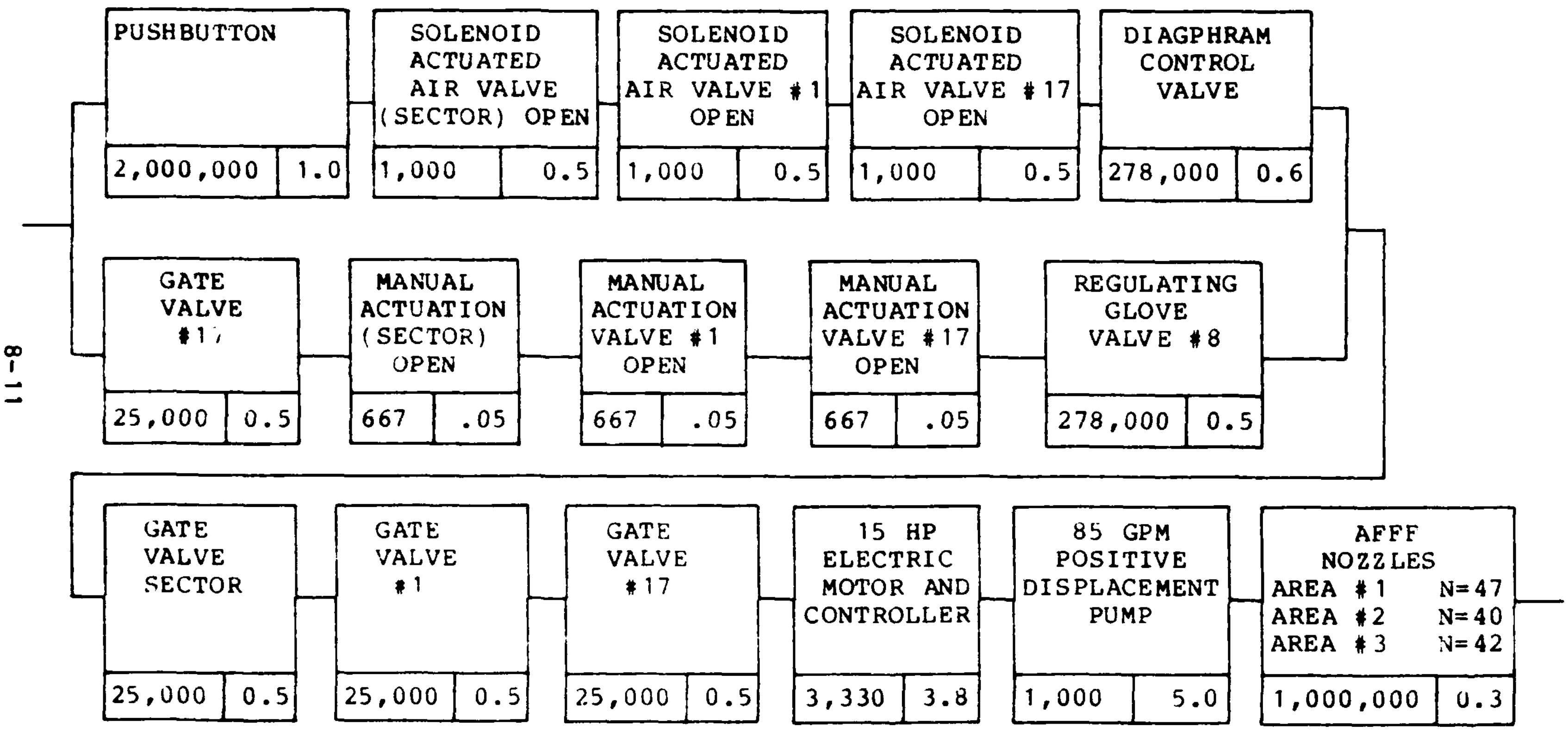
Electric Motor: $A_{EM} = \frac{3330}{3330 + 3.8} = .99886$

85 gpm PD Pump: $A_{PDP} = \frac{1000}{1000 + 5.0} = .99950$

Foam Nozzle: $A_{NOZ} = \frac{1,000,000}{1,000,000 + 0.3} = .9999997$

FIGURE 8-3

FUEL TRANSFER AREA FOAM SYSTEM RELIABILITY/AVAILABILITY BLOCK DIAGRAM



Since there are three independent gate valves, one motor, one pump, and a maximum of forty-seven nozzles required for normal system function, the system availability is approximately:

$$A_{FOAM\ SYS} = (A_{GV})^3 \cdot A_{EM} \cdot A_{PDP} \cdot (A_{NOZ})^{47}$$

$$\begin{aligned} &= (.9998)^3\ (.99886)(.9995)(.9999997)^{47} \\ &= (.9994)(.99886)(.9995)(.99999) \\ &= .9977 \end{aligned}$$

Therefore, the fuel transfer area foam system exceeds the reliability and availability requirements if routine system inspection, test and preventive maintenance procedures are followed:

8.4 Existing AFFF System

There are three AFFF systems currently installed on the Taluga. They are identical except that helicopter pad AFFF system has two hose lines and nozzles. Each system consists of a water motor proportioner, an AFFF tank, a hose and a nozzle. Figure 8-4 is the reliability block diagram of the existing AFFF system.

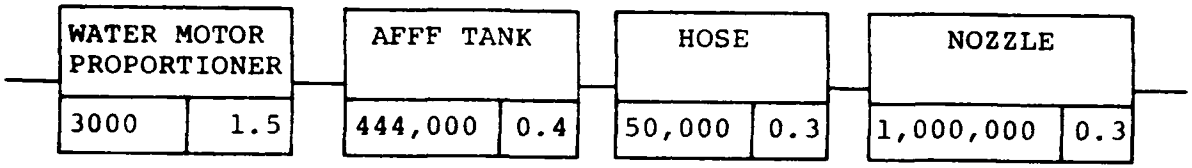
As is true of the fuel transfer area foam system, the reliability is irrelevant because of the short duty cycle of the system. The dominant consideration is the intrinsic steady state availability which can be determined in the following manner:

Water Motor Proportioner: $A_{WMP} = \dfrac{3000}{3000 + 1.5} = .99950$

AFFF Tank: $A_{TNK} = \dfrac{50,000}{50,000 + 0.3} = .999999$

FIGURE 8-4

EXISTING AFFF SYSTEM RELIABILITY/AVAILABILITY BLOCK DIAGRAM



Hose: $A_{HOS} = \dfrac{50,000}{50,000 + 0.3} = .999994$

Nozzle: $A_{NOZ} = \dfrac{1,000,000}{1,000,000 + 0.3} = 1.0$

It is apparent that the water motor proportioner is the driving element in system availability. The helicopter pad with two hoses represents the worst case for existing AAAF system availability.

Helo Pad:

$$A_{AAAF} = (A_{WMP})(A_{TNK})(A_{LBS}^2)(A_{NOZ}^2)$$

$$= (.99950)(.999999)(.999994)^2$$
$$= .999487$$

Other Locations:

$$A_{AAAF} = (A_{WMP})(A_{TNK})(A_{HOS})(A_{NOZ})$$

$$= (.99950)(.999999)(.999994)$$
$$= .999493$$

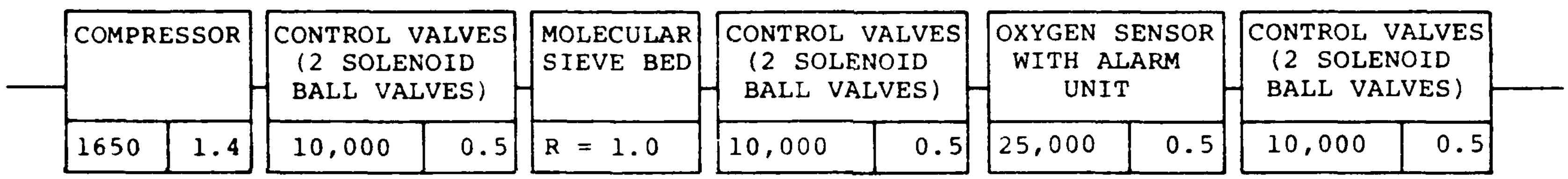
Therefore, it can be concluded that the existing AAAF system comfortably exceeds its reliability and availability requirements.

8.5 Inert Gas System

The type of inert gas system recommended is the pressure swing adsorption unit. This sytem consists of a compressor, a molecular sieve bed, control valves and piping, an an oxygen sensor with alarm assembly. Figure 8-5 is a reliability/availability block diagram for the system. The following calculations determine the availability and reliability of the system.

FIGURE 8-5

INERT GAS SYSTEM - PRESSURE SWING ADSORPTION - RELIABILITY/AVAILABILITY BLOCK DIAGRAM



	$n\lambda$	MTTR	$n\lambda$MTTR
Compressor: $A_{COMP} = \frac{1650}{1650 + 1.4} = .99915$	.000606	1.4	.000848
Control Valves: n=6 $A_{CV} = \frac{10,000}{10,000 + 0.5} = .999950$	.000600	0.5	.000300
Oxygen Sensor: $A_{OS} = \frac{25,000}{25,000 + 0.5} = .999980$	.000040	0.5	.000020
TOTAL	.001246		.001168

Pressure Swing Adsorption System Availability:

$$A_{PSA} = (A_{COMP})(A_{CV})^6(A_{OS})$$

$$\begin{aligned} &= (.99915)(.99995)^6(.99998) \\ &= (.99915)(.99960)(.99998) \\ &= .99873 \end{aligned}$$

Pressure Swing Adsorption System Reliability:

$$R_{PSA} = e^{-n\lambda t}$$

$$\begin{aligned} &= e^{-(.001246)(8766)} \\ &= e^{-10.92} \\ &= .000018 \end{aligned}$$

The results indicate that while system availability will be adequate, the operational reliability is very low. The expected number of failures per year is nearly eleven. There is very little that can be done about the reliability, but an

adequate provisioning of sensor leads, control valves and major compressor components will help insure that the availability prediction is met. Actual experience with inert gas system has borne out the above reliability estimate for present system designs. Considerable work is being done to improve these units and significant improvement in their reliability should be realized over the next few years.

8.6 Emergency Shutdown (ESD) System

The reliability and availability model, see Figure 8-6, of the ESD assumes that all four block valves must be actuated. This is a conservative assumption, but it may be warranted because of the many success paths that may be used to deliver fuel. Also, many of the possible causes of a line or hose rupture are likely to cause a double rupture which in some cases could require all four block valves to be actuated.

The emergency shutdown signal can be initiated at any of seven alarm boxes. If a particular box should be in a failed state, then the sound powered telephones can be used to order initiation at another station. Thus, the reliability block diagram shows the sound powered telephones in active redundancy with the alarm box for seven locations.

The emergency shutdown alarm is given at four stations - the bridge, the engine room and both pumping rooms. The signal consists of an audible alarm and a flashing light. The reliability block diagram shows the flashing light in active redundancy with the audible alarm for four stations.

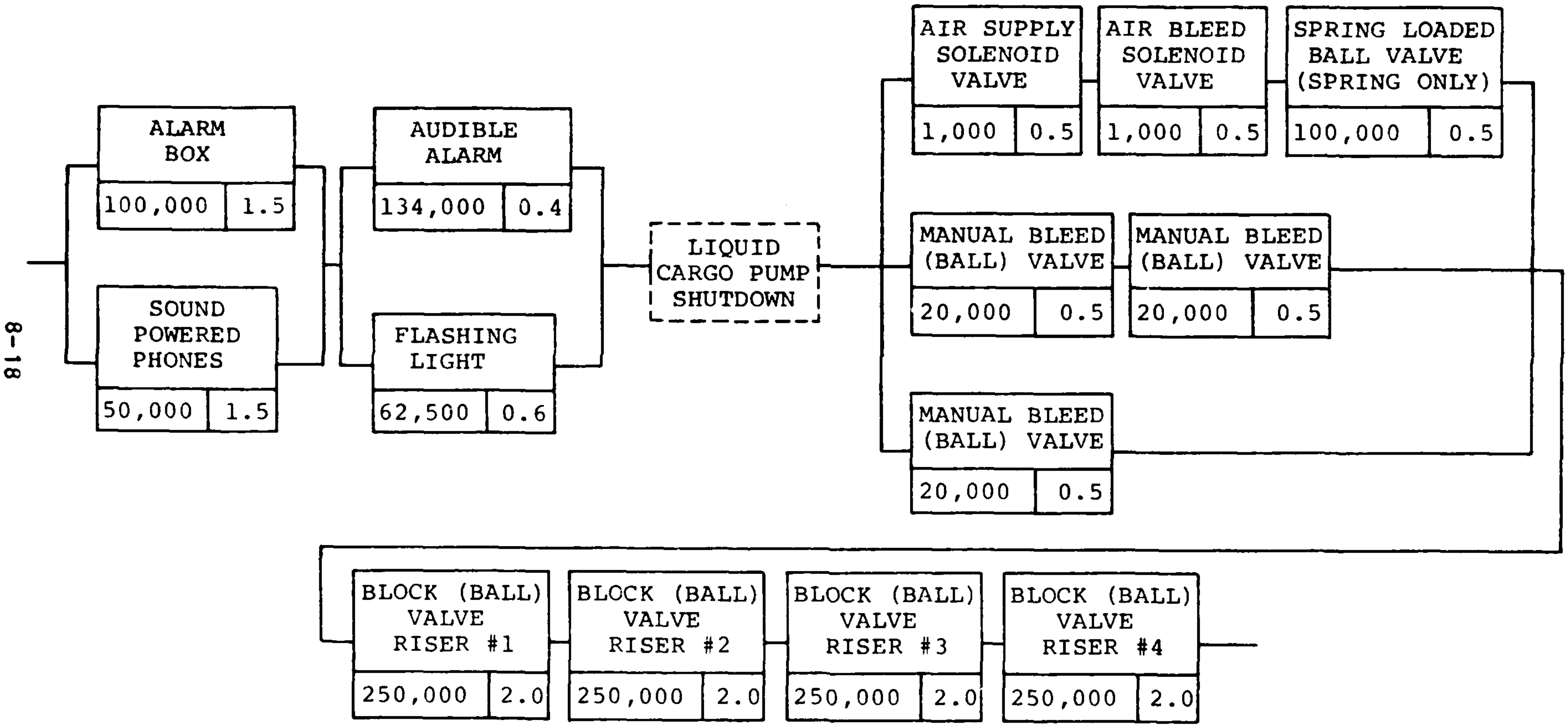
When a signal is given to activate ESD, power is first removed from the pumps and an attempt is made to automatically close the solenoid actuated ball valves by removing power to the air supply solenoid, activating the air bleed solenoid and allowing the spring to drive the ball valve closed. This operation will require 15 seconds.

There are two redundant modes of manual operation. If air pressure is available, then two manual bleed valves can be operated to allow the spring to close the ball valve. If air pressure is not available, then a single manual bleed valve can be operated and the ball valve can be closed manually with a handle.

All of the redundant means of initiating ESD and actuating the valves culminate in closing four block valves at the risers. The block valves in the proposed ESD design

FIGURE 8-6

EMERGENCY SHUTDOWN (ESD) SYSTEM RELIABILITY/AVAILABILITY BLOCK DIAGRAM



are spring loaded ball valves. As stated earlier, the reliability model assumes that all four valves must close for success to be achieved.

By inspection of the block diagram, it is apparent that the reliability and availability of all elements of the ESD except the four ball valves exceeds 0.99999. Effectively, the availability of ESD is the availability of four ball valves.

$$A_{\text{BALL VALVE}} = \frac{250{,}000}{250{,}000 + 2.0}$$

$$= .999992$$

$$A_{\text{4BALL VALVES}} = (.999992)^4$$

$$= .999968$$

The reliability for four valves for one year is as follows:

$$R_{\text{4BALL VALVES}} = e^{-n\lambda t}$$

$$= e^{-4(1/250{,}000)(8766)}$$

$$= e^{-.1403}$$

$$= .8691$$

This reliability calculation can be considered to be conservative since it is predicated on a failure rate for valves that are frequently operated. The valves in the ESD will be required to operate on a infrequent basis and therefore although the calculated reliability of the valves is 0.8691 this is probably adequate to insure a system reliability of 0.85.

8.7 Summary of System Availability and Reliability Calculations

Table 8-1 summarizes the results of section 8.1 through 8.6. The significant results are that the availability requirement of 0.85 is easily exceeded by all systems while the reliability requirement of 0.85 cannot be achieved for some systems. The reliability is not a relevant parameter

for foam systems due to the short duty cycle and the potentially catastrophic results for the ship if foam systems are not instantaneously available. The liquid cargo systems reliability is severely limited by rubber hoses and not much can or should be done about them except for following the test, inspection and replacement schedules which are recommended. The inert gas system is a new design whose reliability is limited by the heavy duty cycle on the compressor and the six solenoid control valves. The inert gas system appears to be the most likely candidate for purchasing high reliability components and insisting on a system design which can demonstrate low mean-time-to-repair (MTTR's) when maintenance is performed by typical enlisted rates.

TABLE 8-1
SUMMARY OF A/R FOR HAZARD CONTROL SYSTEMS

	Availability	Reliability
Fire water system	1.0	1.0
Liquid cargo systems	.9999	.7043
Fuel transfer area foam system	.9977	NA
Existing AFFF system	.9995	NA
Inert gas system	.9987	≈0
Emergency shutdown (ESD) system	1.0	.8691

8.8 Preventive Maintenance

The recommended additions to the fire fighting system for the offshore bulk fuel system storage tanker will not require a significant change in the system preventative maintenance requirement procedures. Examination of the Maintenance Requirement Cards (MRC) and Maintenance Index Pages (MIP) of the Navy's 3M system shows that detailed preventative maintenance schedules exist for the ships fire fighting equipment. The additional fire water and foam system monitor nozzles recommended in this study are similar to existing Navy equipment. Also, preventative maintenance recommendations are available from the commercial suppliers of the specific equipment that is finally selected.

The recommended deck foam sprinkler system contains components that are similar to foam systems that are currently being installed on Navy and commercial tankers. Again, the preventative maintenance procedures for this system will not be subtantially different from those that are

currently in effect for the newer Navy tankers that have a deck foam system.

The shipboard portion of the fuel transfer system has not been substantially modified except for the recommended addition of the ESD. The solenoid operated control valves in this system are the components that will require the most inspection and maintenance. These should be handled by procedures that have already been developed for solenoid control valves and are in use throughout the Navy.

The change in operational mode of the tanker requires that the preventative maintenance schedule for the fuel transfer system be reconsidered. Currently, the MRC's and MIP's base the required system inspection and maintenance on elapsed calendar time and not on operating hours. Since fuel transfer will be taking place on an almost continuous basis, existing preventative maintenance schedules should be reconsidered on the basis of 8766 hours of operation per year. A five to ten fold increase in pumping times compared with typical tanker applications can be expected to require increased preventative maintenance action. Preventative maintenance schedules for this application should be placed on an operating hours basis. Existing weekly actions should remain on a weekly basis with quarterly and annual maintenance activities upgraded to monthly and quarterly intervals, respectively.

The preventative maintenance requirements for the proposed inert gas system are difficult to define at this time. The compressor used in the inert gas system will be similar to existing refrigeration compressors and therefore a similar preventative maintenance schedule can be adopted. The molecular sieve bed used in the system has no obvious counterpart in Navy inventory. Additionally, the exact component make-up of the system will be dependent upon the particular supplier that is selected. Systems of this type are currently being installed in commercial tankers. Preventative maintenance recommendations should therefore be readily available from the manufacturer of the system that is selected.

8.9 Corrective Maintenance

The average weekly corrective maintenance man-hours for typical U. S. Navy tankers is surprisingly low. Examination of the Navy 3M reports shows that from 1 January 1976 to 30 September 1979, the average man-hours per week was only 27.40

for all of those systems that are associated with fuel oil transfer and fire protection.

The Tanker Offshore Fuel Storage and Transfer ship scenario is certain to impose a heavier corrective maintenance load than a typical tanker experience. Analysis of the 3M report reveals that the major contributors to corrective maintenance are the liquid cargo systems and the fire main and associated systems. The increased operating requirements on the fire main will not be significant, but the utilization time of the liquid cargo systems will be about seven times greater than normal. A simplistic approach would be to multiply the fleet average by seven, but this is somewhat pessimistic. Many failure modes are as time dependent as they are dependent upon hours of operation or cycling. Additionally, continuous operation avoids failures associated with start-up and shutdown transients. Also, some failure modes such as rust or corrosion of fuel injectors in diesel engines due to water in diesel fuel are much more likely to occur during downtime than when operating. This is why some failure probabilities on the fault trees are based on demand rather than operating time.

It is probably conservative enough for planning purposes to increase the corrective maintenance time on the liquid cargo systems by a factor of five and the fire main and fire extinguishing systems by a factor of two. Since these systems account for over 90 percent of the relevant system corrective maintenance time, there is little if any error present when the others are ignored. Thus, the projected corrective maintenance times are shown in Table 8-2.

These calculations are conservative but they do not account for the proposed inert gas system and fuel transfer area foam system. The new foam system can be assumed comparable to half the existing ship fire extinguishing systems for manpower planning, but the inert gas system presents some difficulty. The expected number of failures per year is eleven with an MTTR of approximately one hour as shown in Section 8.5. These calculations were based on the assumption that the system is designed for quick access and ease of maintenance with a compressor MTTR of 1.4 hours and solenoid valve MTTR of 0.5 hours. Various sources quote compressor MTTR's as high as 6.0 hours and solenoid valve MTTR's as high as 1.5 hours. If these pessimistic values apply to this inert gas system, then the annual corrective maintenance load could be about 33 hours rather than 11 hours. For planning purposes, the pessimistic values will be used:

TABLE 8-2

ADJUSTED CORRECTIVE MAINTENANCE HOURS FOR EXISTING SYSTEMS

					Hrs per Week
Ventilation	1	x	.00	=	.00
Liquid Cargo	5	x	11.38	=	56.90
Fire Main	2	x	10.66	=	21.32
Fire Extinguishing	2	x	3.62	=	7.22
Scuppers, etc.	1	x	1.10	=	1.10
Filling, Vent & Transfer System-Fuel/Diesel Oil	1	x	.64	=	.64
ADJUSTED CORRECTIVE MAINTENANCE HOURS					87.18

Weekly Average Corrective Maintenance Time

Inert gas system:	$\frac{33}{52} = 0.63$
Fuel transfer area foam system:	3.62
Total for Proposed Systems	4.25

Now the total for all systems can be determined.

Total for Existing Systems		87.18
Total for Proposed Systems		4.25
	TOTAL	91.43 Hrs per week

8.10 Spare Parts Recommendations

The following is a list of spare parts for the systems that have been recommended in this report:

1. Deck Foam System
   Ten (10) sprinkler heads
   Pump seals for concentrate proportioner pump

2. ESD
   One set of controls
     Solenoid control valve
     Fire alarm pull box

   One ball valve operator

3. Fuel transfer system
   Spare hose (sections from tanker to SPM)
   Gas detector head
   Pressure sensor for cargo pump discharge

8.11 Data Base

An extensive investigation was carried out to develop an accurate, statistically well founded set of failure and repair rates. It was originally thought that the U. S. Navy 3-M reports (Maintenance Material Management Reports) would be of great value. This was not the case for MTBF and MTTR data. The problem is that there are no metering devices on the basic ship systems which record operating time.

Therefore, no MTBF's can be computed. At some future time, 3-M may be able to develop a correlation between steaming hours and the operating hours of ship systems such as fuel oil transfer and fire water. If this is achieved, then MTBF's can be determined.

GIDEP is of potential value, but use of the GIDEP system is dependent upon knowing many exact parameters of the components such as pumps, valves and motors for which information is sought. Therefore, GIDEP can be used when sufficient time exists to determine precisely which parameters are required to use the GIDEP system and then visit the ships being analyzed and make extensive notes. This was not possible on this contract due to limitations on time and access to ships.

The approach taken to overcome these problems was to use reliability, maintainability and safety studies such as the Rasmussen Report (WASH 1400), the studies carried out by Litton Industries on the LHA and DD-963 programs, chemical industry risk analyses, and various documents published by DOD agencies. Tables 8-3 and 8-4 identify these data sources.

In the area of corrective maintenance times, the 3-M reports were invaluable. They are the only source of data used in estimating the corrective maintenance time required for this operating scenario.

Code 913 of NAVSEACENPAC was the source of preventive maintenance (PM) data used in determining the additional logistical requirements of the proposed fuel transfer area foam system and the inert gas system.

Table 8-3

FAILURE RATE DATA

COMPONENT	FAILURE MODE	MEDIAN	LOW	HIGH	REFERENCE	REMARKS
Alarm, Audible		$7.5/10^6$			17	
Compressor	Fails to Run	$606/10^6$			20	
Engine, Diesel	Fails to start on demand	$3/10^2D$	$1/10^2D$	1/10d	26	
Box, Alarm	Fails to start on demand	$10/10^6H$			20	
Engine, Diesel	Fails during operation	$6960/10^6D$	$151/10^6H$	$11/500/10^6H$	28,24	
Engine, Gas Turbine	Fails during operation	$577/10^6H$	$40/10^6H$	$1,520/10^6H$	28, 24, 5	
Gaskets	1" x 1/16" Leak	$3/10^6H$	$.1/10^6H$	$100/10^6H$	26	
	Major Leak	$.1/10^6H$			6	Adjusted from minor leak
	Total Failure	$.3/10^6H$			6	Adjusted from minor leak
Hoses	Rupture	$20/10^6H$	$4/10^6H$	$40/10^6H$	6, 9, 23	Higher if not replaced regularly
	1/2" Diameter Leak	$30/10^6H$			6	Adjusted from rupture
	1/8" Diameter Leak	$40/10^6H$			6	Adjusted from rupture

TABLE 8-3 (Continued)

COMPONENT	FAILURE MODE	MEDIAN	LOW	HIGH	REFERENCE	REMARKS
Light, Flashing		$16/10^6$H			20	
Manifolds	?	$10/10^6$H			17	
Motors, Electrical	Fails during operation	$65/10^6$H	$37/10^6$H	$161/10^6$H	28,24	
Nozzle		$1/10^6$H			17	
Oxygen Sensor With Alarm Unit		$40/10^6$H			6	
Proportioner, Water Motor		$333/10^6$H			28	
Packing, Valve	Major Leak	$.6/10^6$H			28	
	Small Leak	$3/10^6$H			6	Adjusted from major leak
Phones, Sound Powered		$20/10^6$H			20	
Pumps, Centrifugal	Fails to run normally	$298/10^6$H	$113/10^6$H	$550/10^6$H	28, 24	
Pumps, Pos. Displ.	Fails to start	$1/10^3$D	$3/10^4$D	$3/10^3$D	26	
	Fails to run normally	$152/10^6$H	$61/10^6$H	$485/10^6$H	24	

TABLE 8-3 (Continued)

COMPONENT	FAILURE MODE	MEDIAN	LOW	HIGH	REFERENCE	REMARKS
Pipes (>3")	Rupture	$1/10^{10}H$	$3/10^{12}H$	$3/10^{9}H$	26	
(<3")	Rupture	$1/10^{9}H$	$3/10^{11}H$	$3/10^{8}H$	26	
Tank, AFFF		$2.75/10^{6}H$			17	
Turbine, Steam	Fails to run normally	$53/10^{6}H$			5	
Valve, Block (Ball)		$4/10^{6}H$			17	
Valves, Block (Gate)		$4/10^{5}H$			5	Adjusted from Fixed Ground Environment
Valve, Check	Fails to Open	$1/10^{4}D$	$3/10^{5}D$	$3/10^{4}D$	26	
	Reverse Leak	$3/10^{7}H$	$1/10^{7}H$	$1/10^{6}H$	26	
	External Leak or Rupture	$1/10^{9}H$	$1/10^{9}H$	$1/10^{7}H$	26	
Valves, Manual	Fails to Open	$1/10^{4}D$	$3/10^{5}D$	$3/10^{4}D$	26	
	Leak Across Valve	$1/10^{6}D$	$1/10^{7}H$	$5/10^{6}H$	26, 6, 13	
	External Leak or Rupture	$1/10^{8}H$	$1/10^{9}H$	$1/10^{7}H$	26	

TABLE 8-3 (Continued)

COMPONENT	FAILURE MODE	MEDIAN	LOW	HIGH	REFERENCE	REMARKS
Valves, Motor Operated	Fails to Operate	$1/10^3$D	$3/10^4$D	$3/10^3$D	26	
	Leak Across Valve	$1/10^6$H	$1/10^7$H	$5/10^6$H	26, 6, 13	
	Plugged	$1/10^4$D	$3/10^5$D	$3/10^4$D	26	
	External Leak or Rupture	$1/10^8$H	$1/10^9$H	$1/10^7$H	26	
Valves, Solenoid Operated	Fails to Operate	$1/10^3$D	$3/10^4$D	$3/10^5$D	26	
	Fails to Operate	$100/10^6$H			28	
	Leak Across Valve	$1/10^6$H	$1/10^7$H	$5/10^6$H	26, 6, 13	
	Plugged	$1/10^4$D	$3/10^5$D	$3/10^4$D	26, 6	
	External Leak or Rupture	$1/10^8$H	$1/10^9$H	$1/10^7$H	26	
Valve, Vacuum Relief	Fails to Operate	$3/10^5$D	$1/10^5$D	$1/10^4$D	26	

TABLE 8-3 (Continued)

COMPONENT	FAILURE MODE	MEDIAN	LOW	HIGH	REFERENCE	REMARKS
Valve, Relief	Fails to Open	$1/10^5$D	$3/10^6$D	$3/10^5$D	26	Also Applies to Press. Reg. Bypass
	Premature Open	$1/10^5$H	$3/10^6$H	$3/10^5$H	26	
	External Leak or Rupture	$1/10^8$H	$1/10^9$H	$1/10^7$H	26, 6	
Weld	8" x 1/16" Leak	$1/10^9$H	$1/10^{10}$H	$1/10^7$H	26	
	1" x 1/16" Leak	$3/10^9$H			6	Adjusted from Major Leak

TABLE 8-4

MEAN TIME TO REPAIR DATA

COMPONENT	MEAN TIME TO REPAIR			REFERENCE	REMARKS
	Median	Low	High		
Alarm, Audible	0.4			17	
Compressor	1.4		6.0	20	
Engine, Diesel	8.1	4.1	12.7	24	
Box, Alarm	1.5			20	
Engine, Gas Turbine	8.2	3.5	12.3	24	
Gaskets	1.0	0.5	4.0	6	
Hoses	2.0	0.5	4.0	6	Replace
Light, Flashing	0.6			17	
Nozzle	0.3			17	
Motor, Electrical Fuel Oil XFER	3.8	7.8	21.0	24	
Motor, Electrical Fire Water	6.6			20	
Oxygen Sensor With Alarm Unit	0.5			6	
Proportioner, Water Motor	1.5			17	

TABLE 8-4 (Continued)

COMPONENT	MEAN TIME TO REPAIR			REFERENCE	REMARKS
	Median	Low	High		
Phones, Sound Powered	1.5			20	
Pumps, CTFGL Fire Water	3.2	2.2	4.2	20	
Pumps, CTFGL Fuel Oil XFR	8.0	7.6	9.5	24	
Pumps, Pos. Displ.	5.0			24	
Tank, AFFF	0.4			17	
Turbine, Steam	5.3			24	5.3 on 134 8.2 on 154 [illegible].5 on 137
Valves, Block (Gate)	2.0	0.5	6.0	6	
Valves, Check	1.5	1.0	4.0	6	
Valves, Motor Operated	1.5	0.5	4.0	6	
Vavles, Solenoid Operated	1.0	0.5	2.0	6	
Valves, Vacuum Operated	2.0	1.0	3.0	6	
Valve, Relief	2.0	1.0	3.0	26	
Weld					
8" x 1/16" Leak	8.0	4.0	16.0	6	Assumes permanent repair is made

TABLE 8-4 (Continued)

COMPONENT	MEAN TIME TO REPAIR			REFERENCE	REMARKS
	Median	Low	High		
Weld (Cont.)					
1" x 1/16" Leak	8.0	4.0	16.0	6	Assumes permanent repair is made
Pipe Section					
<3"	16.0	8.0	32.0	6	
>3"	18.0	10.0	34.0	6	

SECTION 9

SUMMARY

The technique of fault tree analysis has been used in this study to identify potential cargo fuel spill sources, volumes and probabilities for the offshore bulk fuel storage system. Using this technique in conjunction with operating data for a T3 tanker the following results have been obtained:

° Small cargo fuel leaks from transfer piping and hoses can go undetected for several hours unless spill detection is provided.

° Large spills, such as that subsequent to a cargo fuel transfer line severing, can be detected in the cargo pump room by use of pressure detection on the discharge side of the cargo pumps.

° Transfer hoses are the most probable source of spills. This is due to the wear and tear on hoses caused by wave action. Calculations show that the probability of a cargo transfer hose rupture is 50% given a one year operating time period.

Based on these findings we recommend the following corrective actions:

° A roving deck watch should be provided aboard the tanker to detect spills - especially unignited spills. Given the design constraints for the proposed mission we found no spill detector that would reliably detect unignited spills on either the ship's deck or in the sea about the ship.

° A remote manual actuated emergency shutdown system (ESD) for cargo transfer should be provided. This will allow ship's personnel to stop fuel flow in about 25 seconds subsequent to detection of a spill.

° The cargo transfer hoses between the tanker and SPM must be inspected and tested on a regular basis - at least every three months. Based on industry's experience with SPM hoses, inspection and testing of hoses as described in Section 2 of this study is a critical item.

Incorporation of this recommendation will provide for early spill detection, limit the potential amount of fuel spilled and reduce the potential for any spill occurring. For small rate spills the roving deck watch reduces the expected spill volumes by a factor of 15. The ESD system would reduce potential spill volume due to major systems failures by a factor of 2.

Cargo fuel spills can ignite. The potential consequences of cargo fuel spill fires have been computed and the following found.

- Spills confined to drip pans, about 250 gallons, or small deck areas present no major risk to the ship if extinguished by ship board fire fighting crews. These fires can be extinguished by shipboard fire fighters using foam handlines or monitor nozzles.

- Spills greater than 250 gallons aboard the tanker would create increased risk to the tanker and fire fighters. Based on calculations contained in this report spills greater than 250 gallons are probable during a one year mission. The ability of fire crews to handle larger fires is subject to considerable doubt. Aboard the USNS Taluga there are many deck areas containing deck piping that cannot readily be reached with the existing foam system.

Based on these findings, we recommend the following:

- The tanker ship used as the offshore storage vessel should be provided a deck foam fire fighting system that can reach any area of the pipe deck. Either monitor nozzles or a fixed pipe foam sprinkler system are satisfactory to most regulatory bodies for this service. We prefer the fixed pipe sprinkler system which has already been adopted by the Navy for its newest tankers.

- A fixed pipe sprinkler system for the USNS Taluga is described in the report.

Cargo tank gas inerting systems are provided aboard newer Navy tankers. Further the U. S. Coast Guard now requires that all new tankers be equipped with gas inerting systems and older tankers greater than 20,000 DWT be retrofitted with a gas inerting system. In view of the proposed objectives of the mission, we strongly recommend that the ship(s) used in the proposed service be provided a cargo tank inerting system.

Table 9-1 presents a summary of recommended equipment additions to a tanker used as the storage vessel in the proposed offshore bulk fueling system. Most tankers built since 1972 will be equipped with the recommended deck foam and inert gas systems.

Analysis of availability data indicates that all recommended additional systems have availability significantly in excess of the contract requirement of 0.85. Reliability requirements are met with a substantial margin by the fire water system, and the fire foam system. The proposed ESD system's estimated reliability of .8691 exceeds the reliability requirement by a small margin. The reliability estimated for the liquid cargo system of .7043 falls far short of the required .85. This is due primarily to the failure rate that can be expected for the rubber cargo transfer hose. The only means for improvement in this area appears to be a substantial improvement in the quality of the hose. At the very least this will require a special procurement activity. The inert gas system also does not meet the reliability requirement. Reliability problems of this system are well recognized in the commercial tanker business and a substantial effort is in progress to improve the reliability of these systems.

TABLE 9-1

LIST OF RECOMMENDED ADDITIONAL EQUIPMENT

1.	Gas Detectors	4
2.	Emergency Shutdown System	4 ball valves 4 actuators 7 fire alarm pull boxes
3.	Fire Water Monitor Nozzle	1
4.	Inert Gas System	1 nitrogen system
5.	Deck Foam Sprinkler System	1 for Taluga
6.	Foam Monitor Nozzles	3
7.	Portable Foam Nozzles	3
8.	Foam Concentrate Tank	1 for Taluga system
9.	Foam Concentrate Tank	1 for Sealift class
10.	Pressure Sensors	3 for Taluga system 4 for Sealift class

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